Operational Snow Hydrology

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Cold Regions Research and Engineering Laboratory

US Army Corps
of Engineers

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Operational Hydrology

Assessment of current water resources for decision support in project management, flood or drought forecasting, or military operations.

CRREL's role:

- Research and support in cold regions
    - Develop new or improved techniques, models and data
    - Enhance understanding of complex problems

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Snow Hydrology

Snow hydrology is the science of estimating the amount of snow water equivalent distributed across a watershed, and the volume and timing of run-off from the snow cover.

Involves:

- Snow Physics
- Snow Data
- Snowmelt modeling

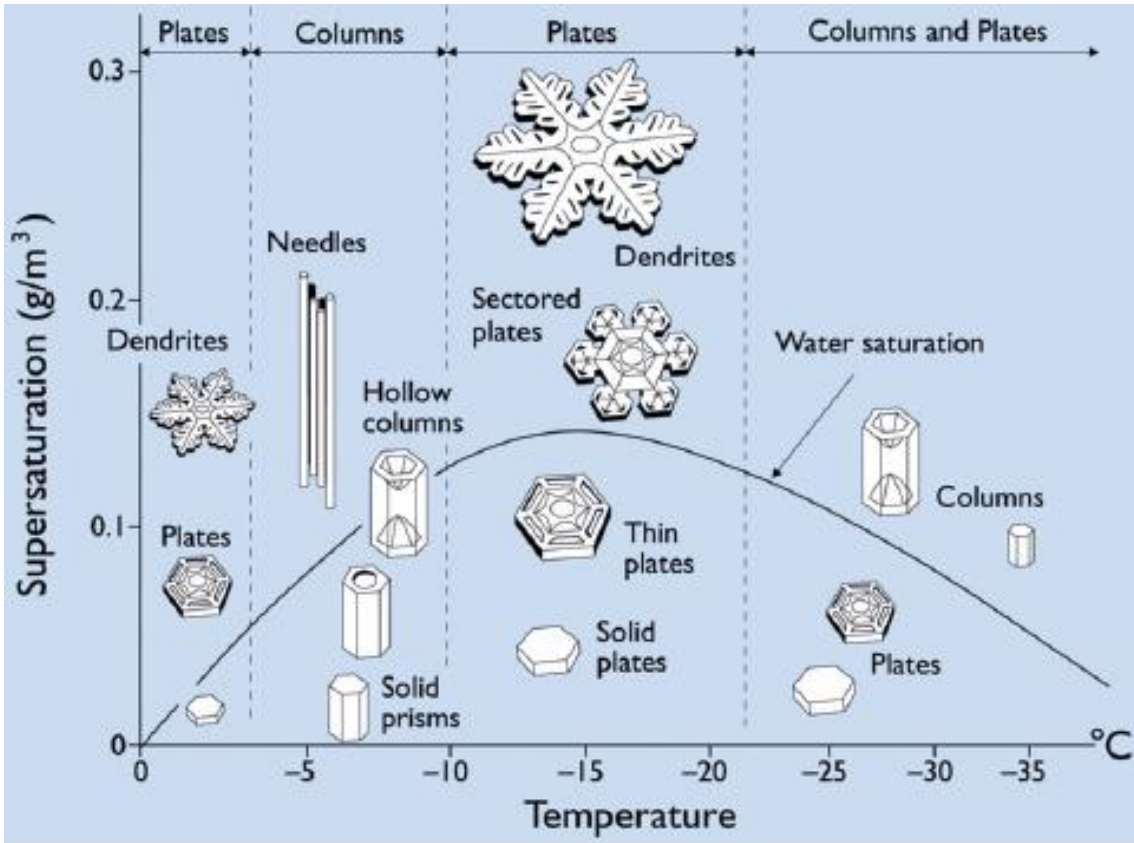**US Army Corps of Engineers**

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Overview

- Snow Physics – characteristics and formation
- Snow Data Collection
- Snow Modeling
- Operational examples:
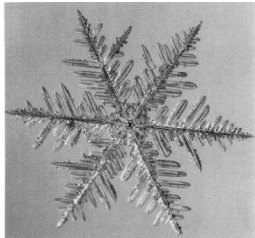 - Military Support
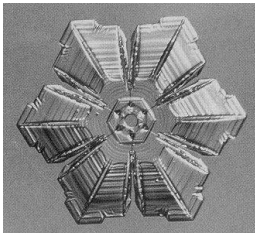 - 3 Case Studies

**US Army Corps
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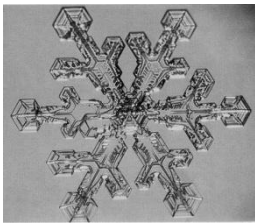
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Snow Crystal Formation
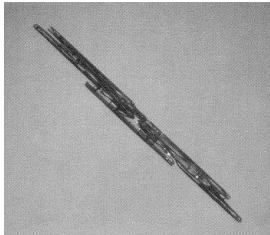

A-Axis Growth

Dendrite

Sectored Plate

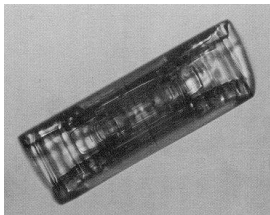Dendritic Sectored Plate

C-Axis Growth

Needle

Prism (Column)
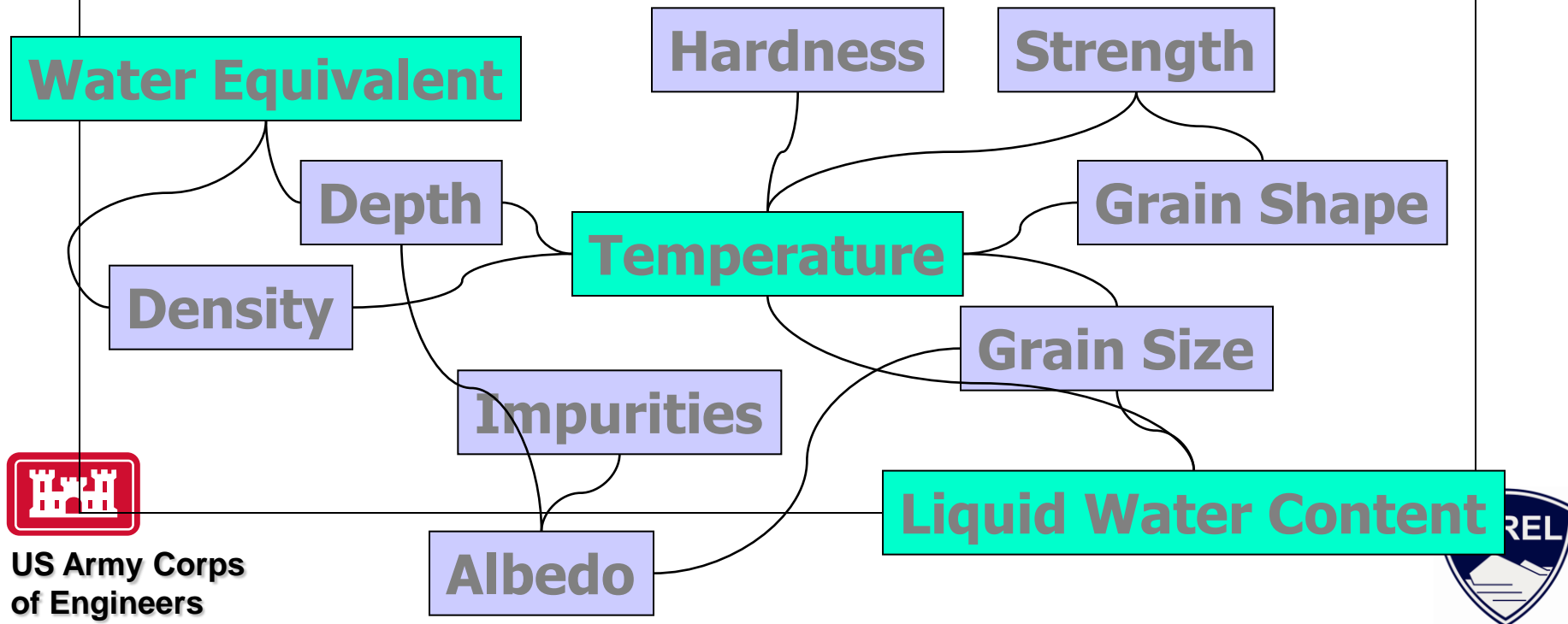
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Snow Pack Characteristics

- Primary physical characteristics of deposited snow

Water Equivalent

Hardness   **Strength**

Depth

Temperature   **Grain Shape**

Density

Grain Size

Impurities

Liquid Water Content

Albedo

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of Engineers

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Snow Pack Characteristics

- **Snow Water Equivalent (SWE)**
  - The height of water if a snow cover is completely melted, on a corresponding horizontal surface area.

  –

    - Snow Depth x (Snow Density/Water Density)

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Density of Snow Cover

Snow Type	Density (kg/m^3)	Snow Depth for One Inch Water
Wild Snow	10 to 30	98" to 33"
Ordinary new snow immediately after falling in still air	50 to 65	20" to 15"
Settling Snow	70 to 90	14" to 11"
Average wind-toughened snow	280	3.5"
Hard wind slab	350	2.8"
New firn snow	400 to 550	2.5" to 1.8"
Advanced firn snow	550 to 650	1.8" to 1.5"
Thawing firn snow	600 to 700	1.6" to 1.4"

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snow physics
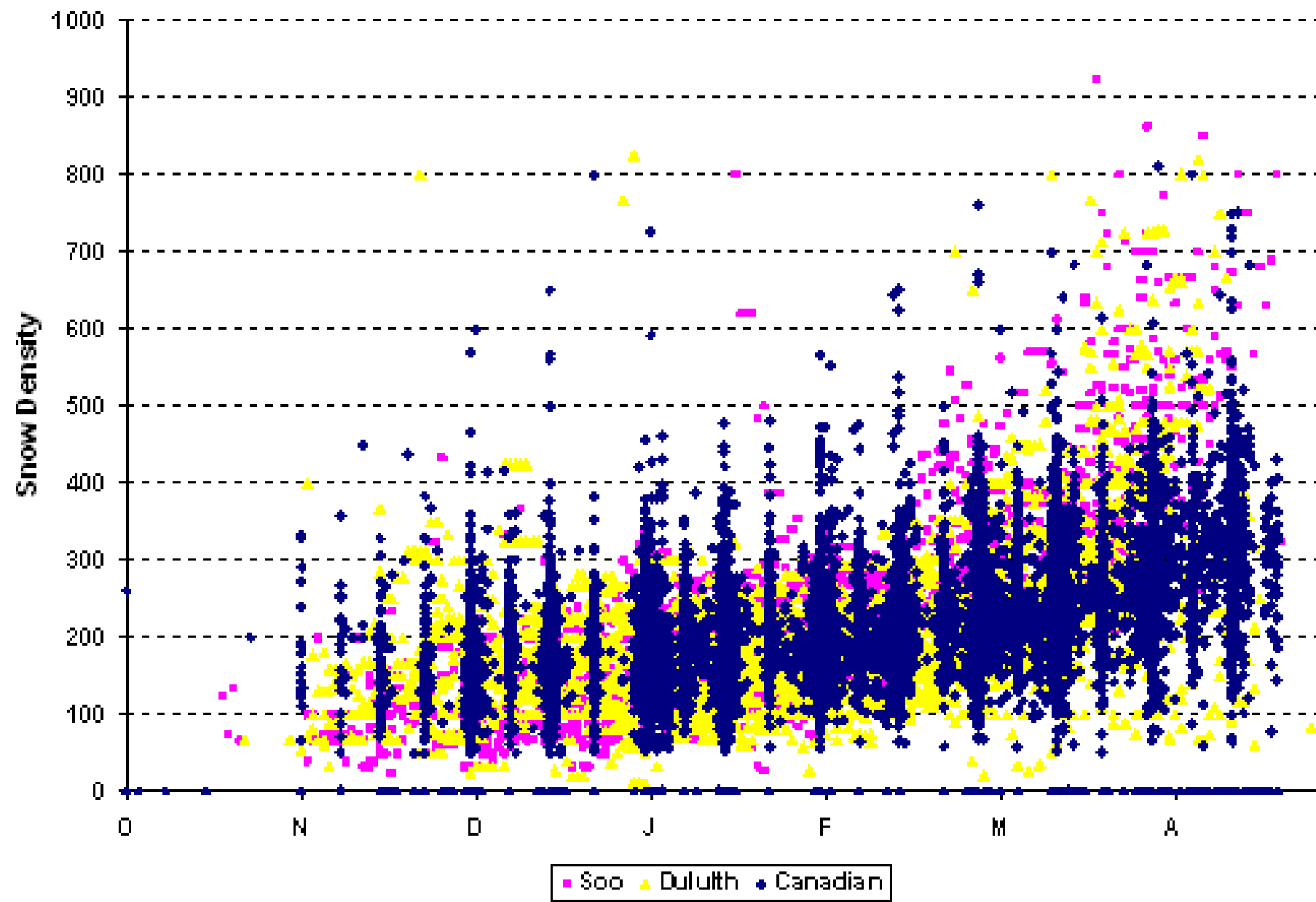
Snow Pack Characteristics

- ## **Liquid Water Content**
  - ### Wetness, Percentage by volume

Term	Remarks	Approximate Range
Dry	Usually T < 0°C, but can occur at any temperature up to 0°C. Little tendency for snow grains to stick together.	0%
Moist	T = 0°C. The water is not visible even at 10x magnification. Has a distinct tendency to stick together.	<3%
Wet	T = 0°C. The water can be seen at 10x magnification by its miniscus between grains, but cannot be pressed out by squeezing snow (pendular regime).	3-8%
Very Wet	T = 0°C. The water can be pressed out by squeezing snow, but there is an appreciable amount of air (funicular regime).	8-15%
Slush	T = 0°C. The snow is flooded with water and contains a relatively small amount of air.	>15%

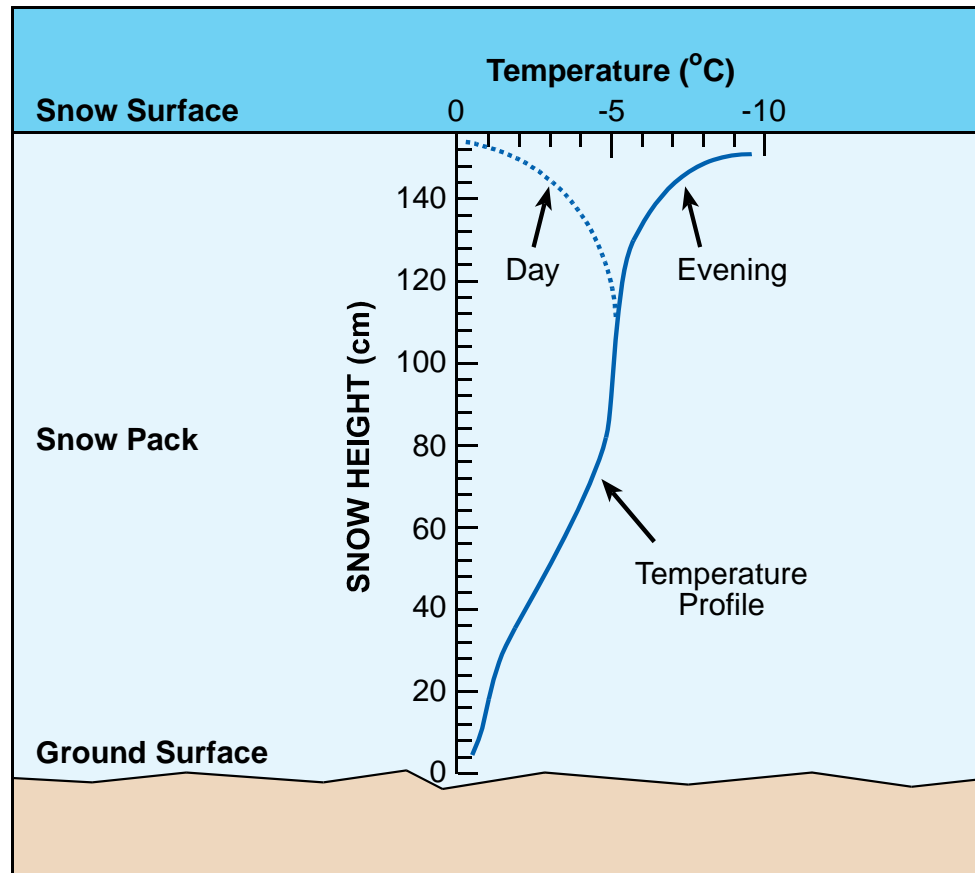**US Army Corps of Engineers**

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Snow Characteristics

- Temperature
  - Two basic situations:
    - Variation in temperature between the top of the snow pack and the ground
      - Temperature Gradient
      - Largely determined by thickness of snow pack and the mean snow surface temperature
        » Base of snow pack is usually near 0^oC
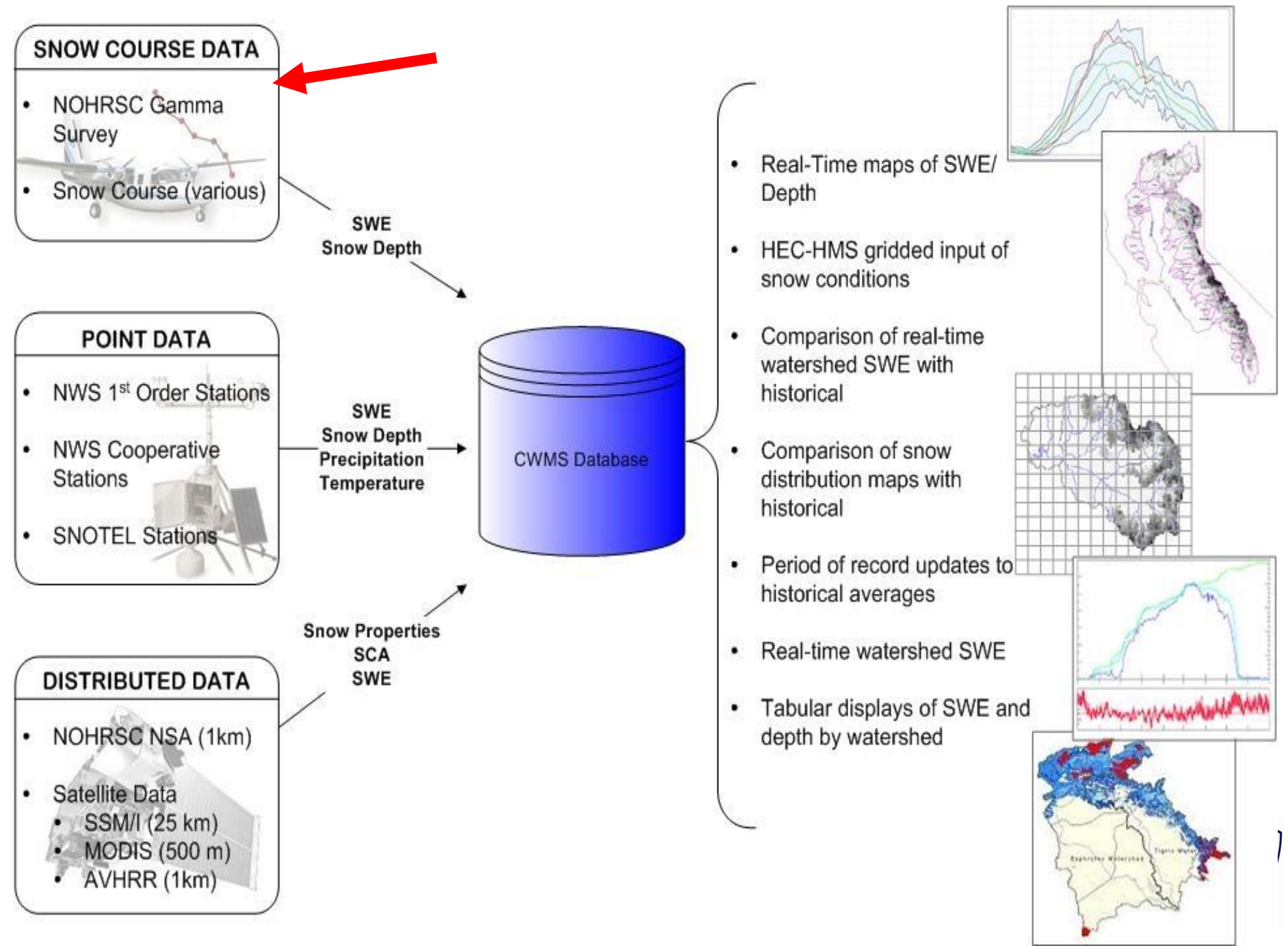   - No temperature gradient
      - Isothermal

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Snow Characteristics

- Diurnal Temperature Gradients

snow data collection

SNOW COURSE DATA
- NOHRSC Gamma Survey
- Snow Course (various)

SWE
Snow Depth

POINT DATA
- NWS 1st Order Stations
- NWS Cooperative Stations
- SNOTEL Stations

SWE
Snow Depth
Precipitation
Temperature

CWMS Database

Snow Properties
SCA
SWE

DISTRIBUTED DATA
- NOHRSC NSA (1km)
- Satellite Data
  - SSM/I (25 km)
  - MODIS (500 m)
  - AVHRR (1km)

- Real-Time maps of SWE/ Depth
- HEC-HMS gridded input of snow conditions
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- Period of record updates to historical averages
- Real-time watershed SWE
- Tabular displays of SWE and depth by watershed

Snow Course Data
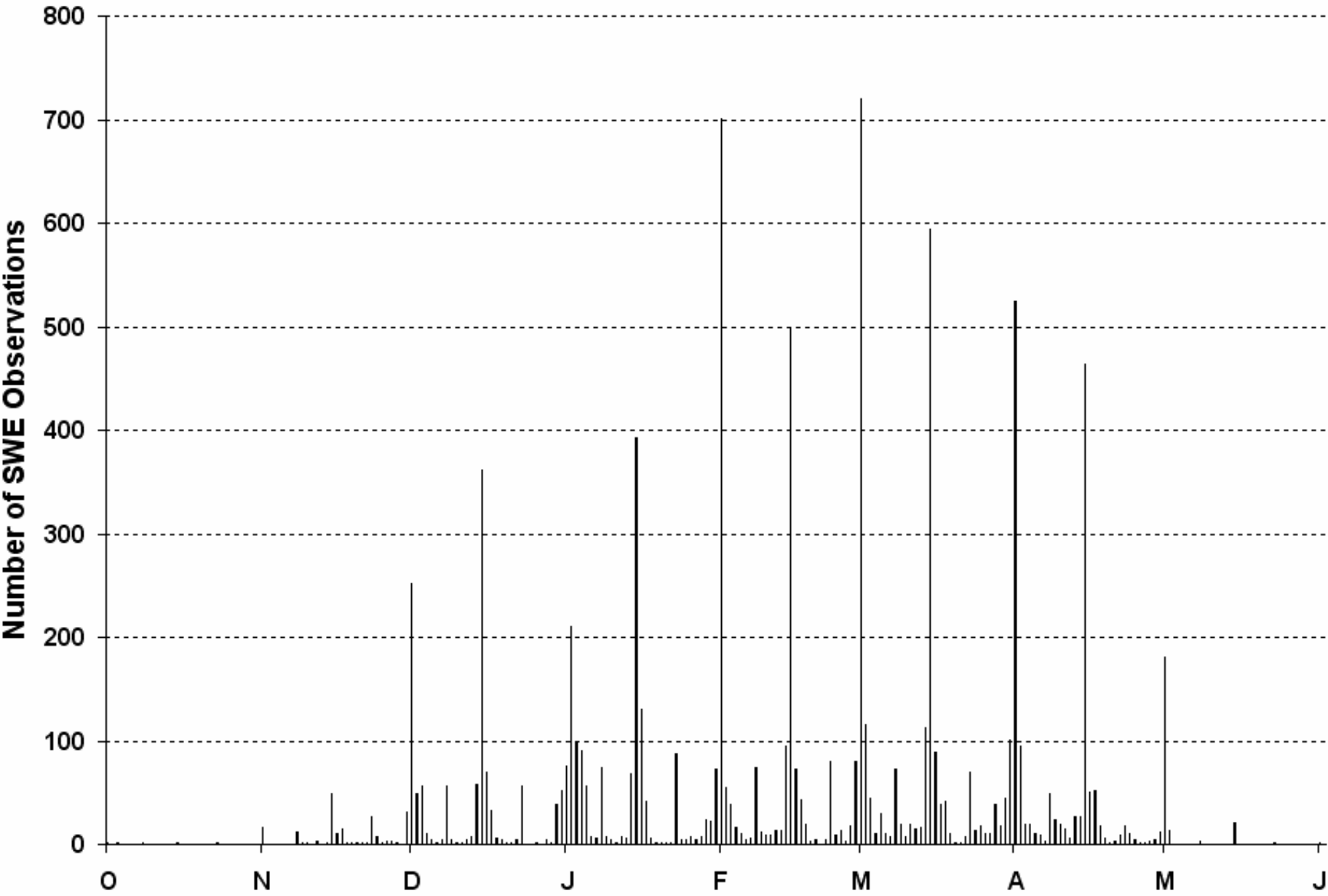

US Army Corps
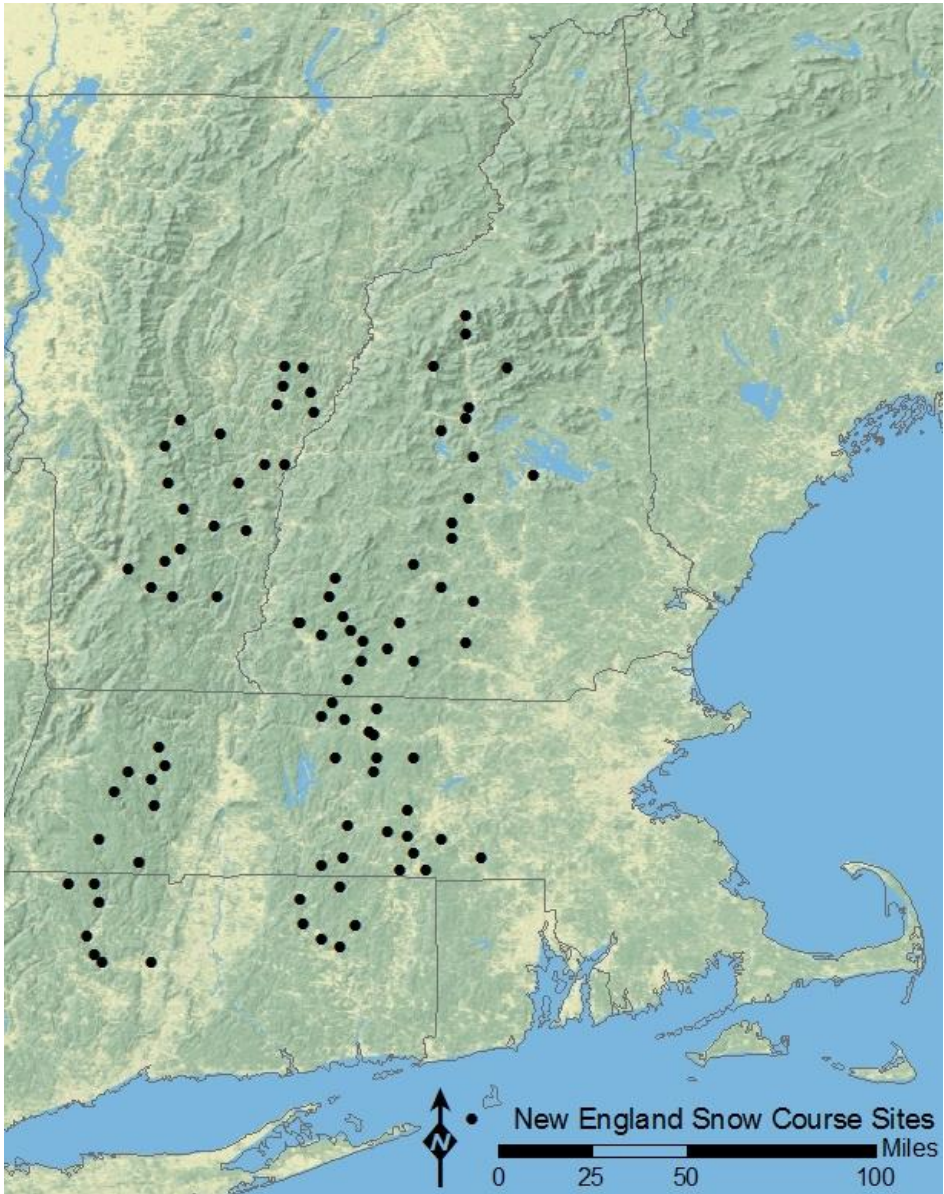of Engineers

Chena Basin, Fairbanks, AK
April 2011 Snow Course

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Snow Course Information for Lake Superior Watershed, Canada
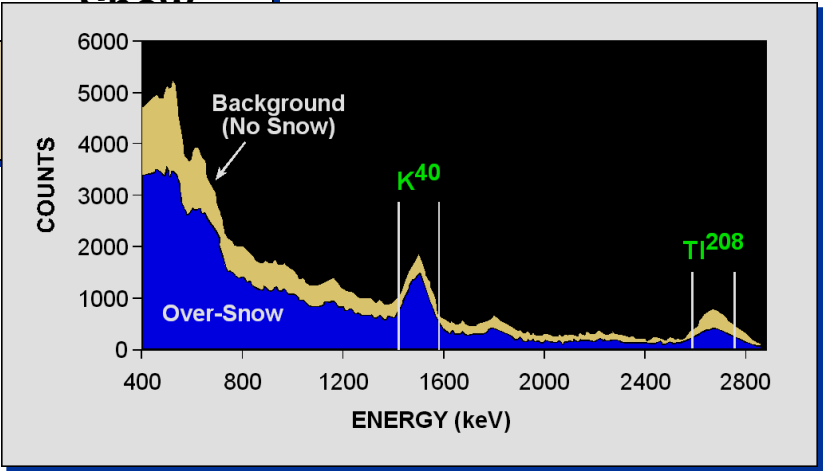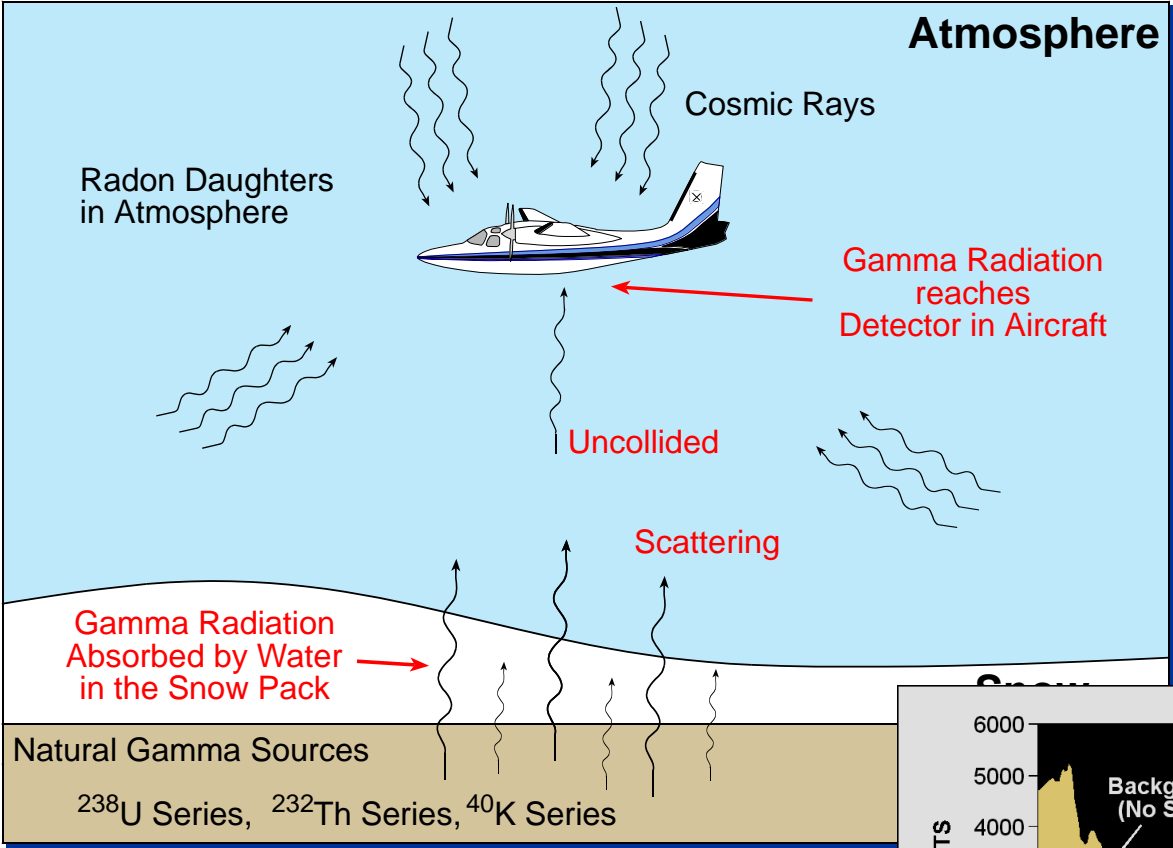
Snow Course Sites in New England

Airborne Snow Survey Program

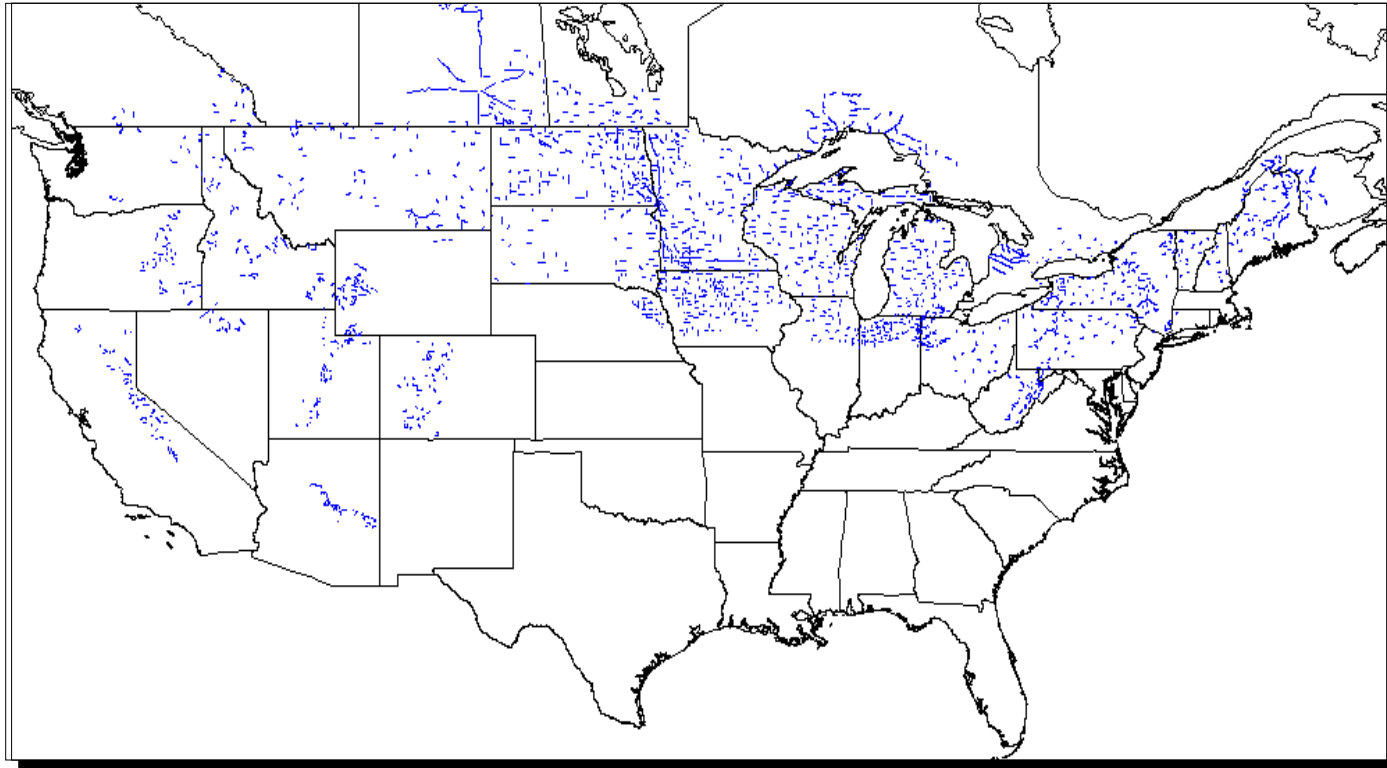– **Snow Water Equivalent (SWE) estimated from attenuation of naturally occurring terrestrial gamma radiation.**

- Typical flight line is 16 km long, measuring a ground swath 3000 m wide.
  - Measures average SWE over area of ~5 km^2
- 1800 flight lines throughout coterminous U.S.
- Two twin-engine aircraft fly ~900 lines/year.

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Airborne Snow Survey Program

Atmosphere

Cosmic Rays

Radon Daughters in Atmosphere

Gamma Radiation reaches Detector in Aircraft

Uncollided

Scattering

Gamma Radiation Absorbed by Water in the Snow Pack

Snow

Natural Gamma Sources

^{238}U Series, ^{232}Th Series, ^{40}K Series

Background (No Snow)

K^{40}

Tl^{208}

Over-Snow

COUNTS — 0, 1000, 2000, 3000, 4000, 5000, 6000

ENERGY (keV) — 400, 800, 1200, 1600, 2000, 2400, 2800

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Airborne Snow Survey Program

2,187 Flight Lines

31 States, 8 Provinces

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snow data collection

SNOW COURSE DATA

- NOHRSC Gamma Survey
- Snow Course (various)

SWE
Snow Depth

POINT DATA

- NWS 1st Order Stations
- NWS Cooperative Stations
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SWE
Snow Depth
Precipitation
Temperature

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  - AVHRR (1km)

Snow Properties
SCA
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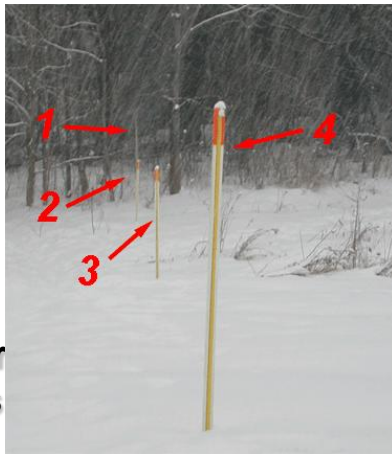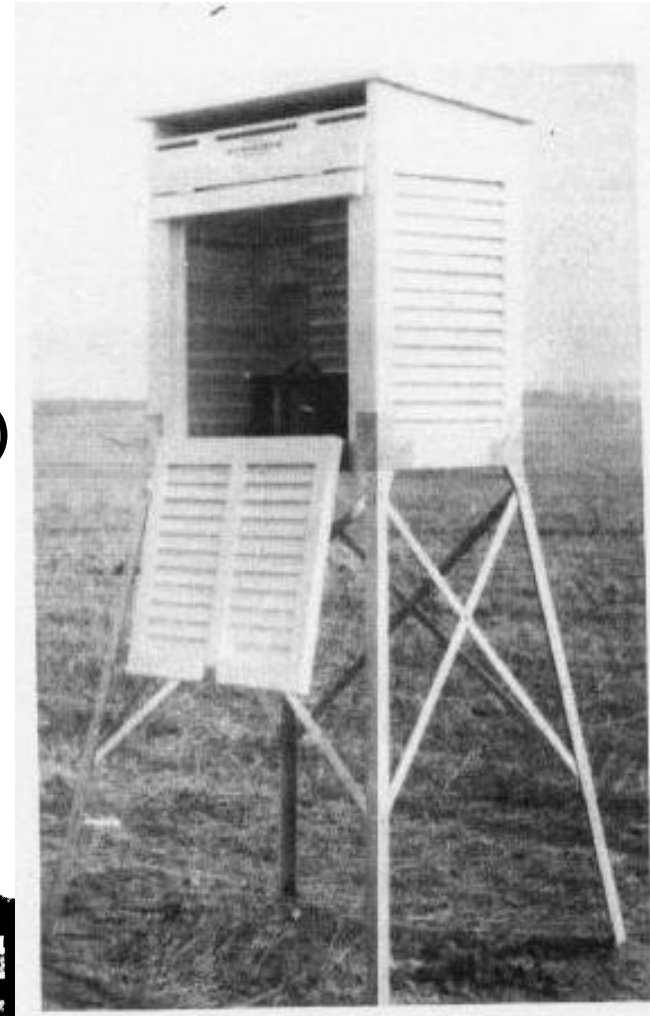
Point Data

- Meteorological Stations
  - Snow Depth
  - Snow Water Equivalent (SWE)
  - Snow Fall
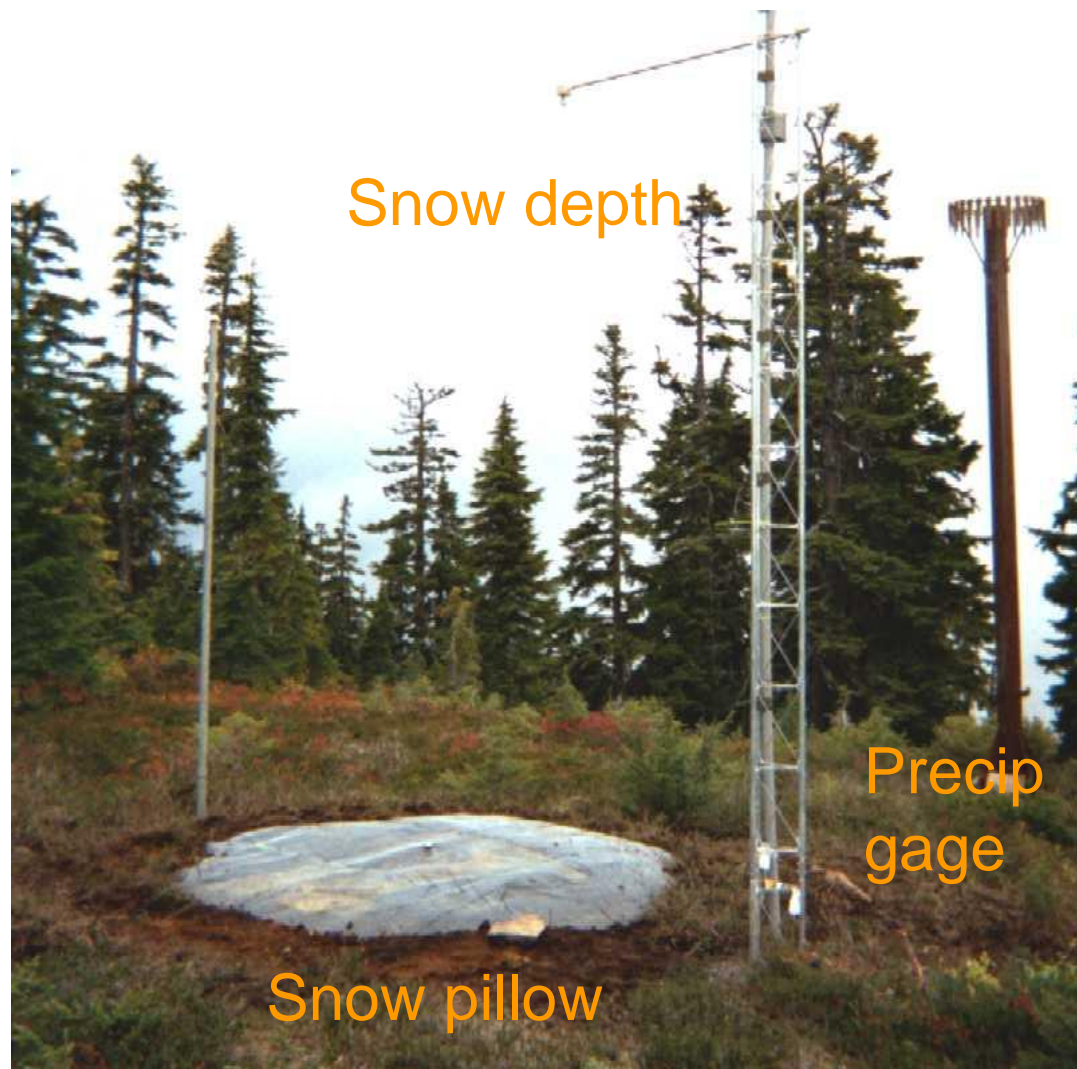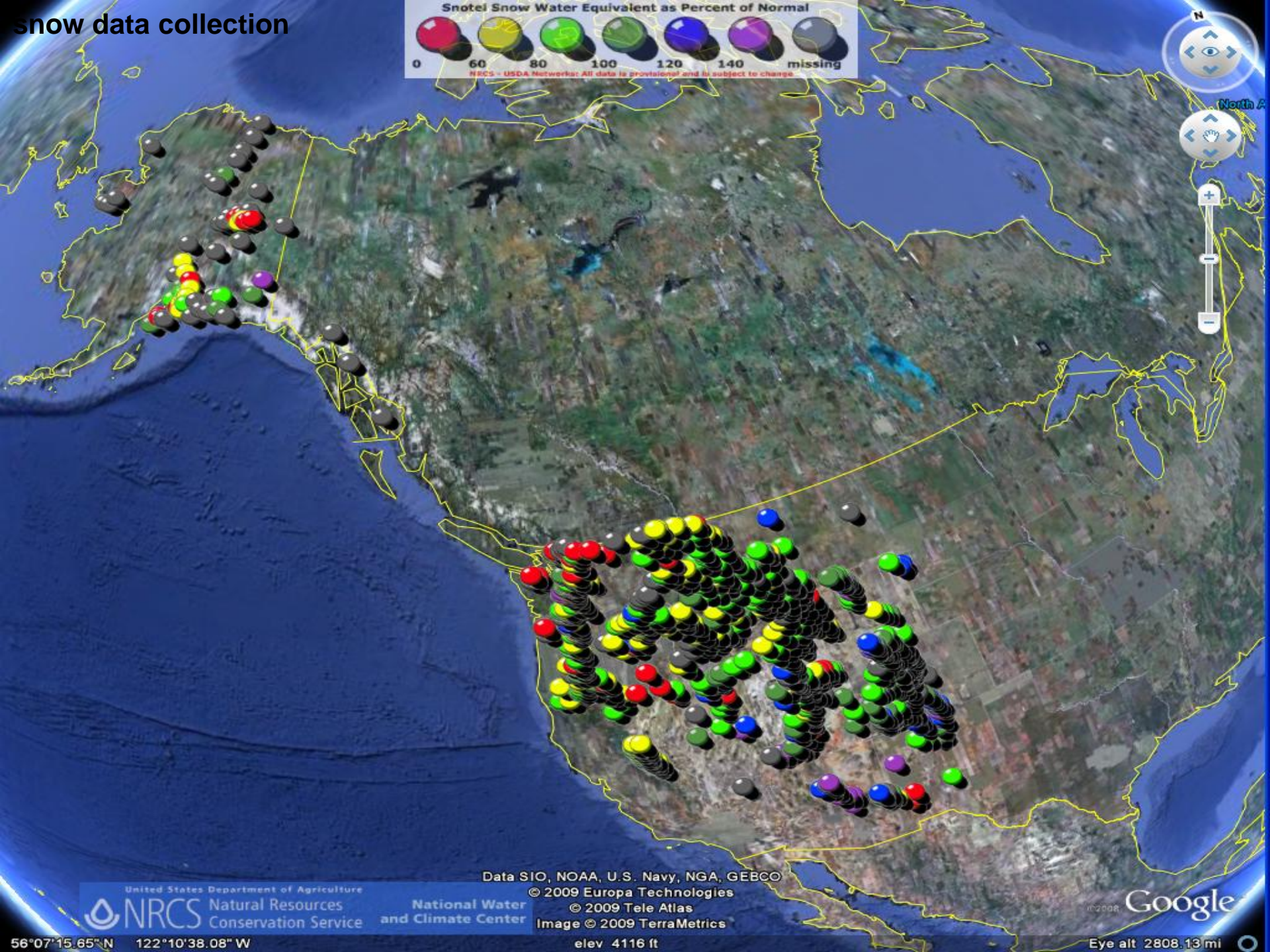 - Precipitation (under catch)

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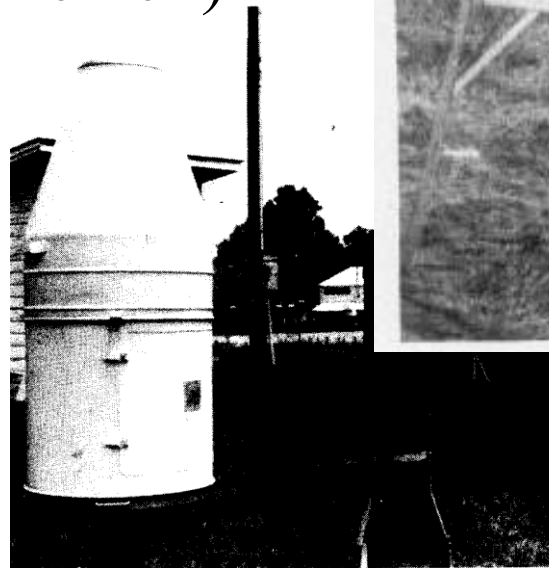
Point Data

- SNOTEL

  - SWE
  - Temperature
  - Precipitation
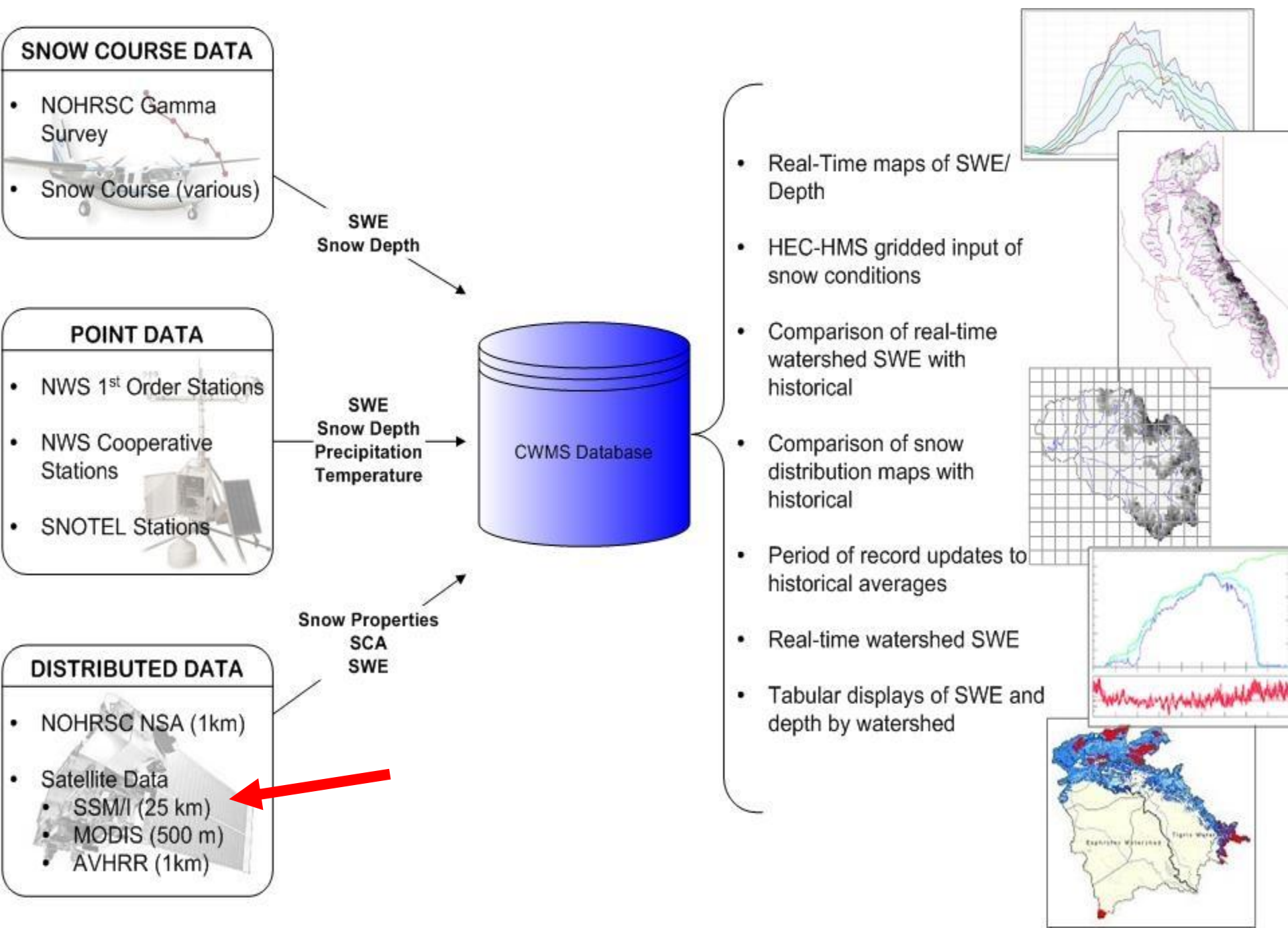 - Snow depth
  - Meteor burst telemetry

Snow depth

Precip gage

Snow pillow

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snow data collection

snow data collection

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Satellite Snow Data

- Snow Water Equivalent – Passive Microwave
  - Special Sensor Microwave/Imagers (SSM/I)
  - Advanced Microwave Scanning Radiometer-EOS (AMSR-E)

- Snow Covered Area - Optical
  - Moderate Resolution Imaging Spectroradiometer (MODIS)
  - Advanced Very High Resolution Radiometer (AVHRR)
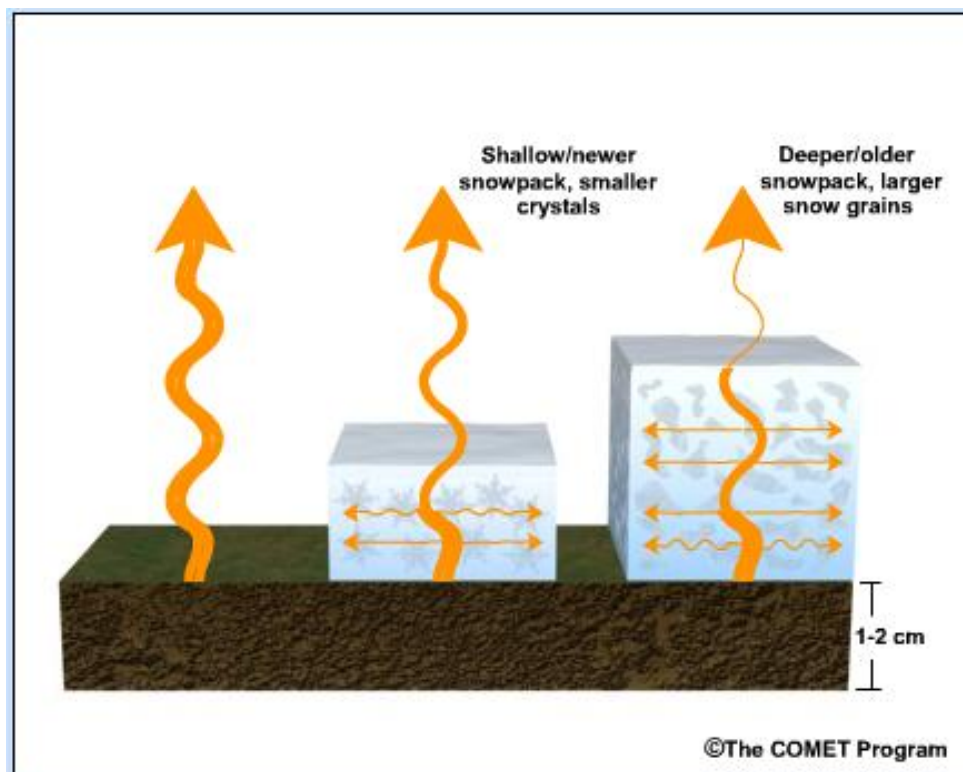
- New satellites every year

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Satellite Passive Microwave

- Passive microwave sensors measure natural microwave emissions (brightness temperature) from the Earth's surface and atmosphere
  - Precipitation
  - oceanic water vapor
  - near-surface wind speed
  - soil moisture
  - snow cover
  - sea ice parameters

- Polar Orbiting

- Pros
  - Complete coverage of Earth twice per day
  - Can see through clouds and at night
  - Inexpensive

- Cons
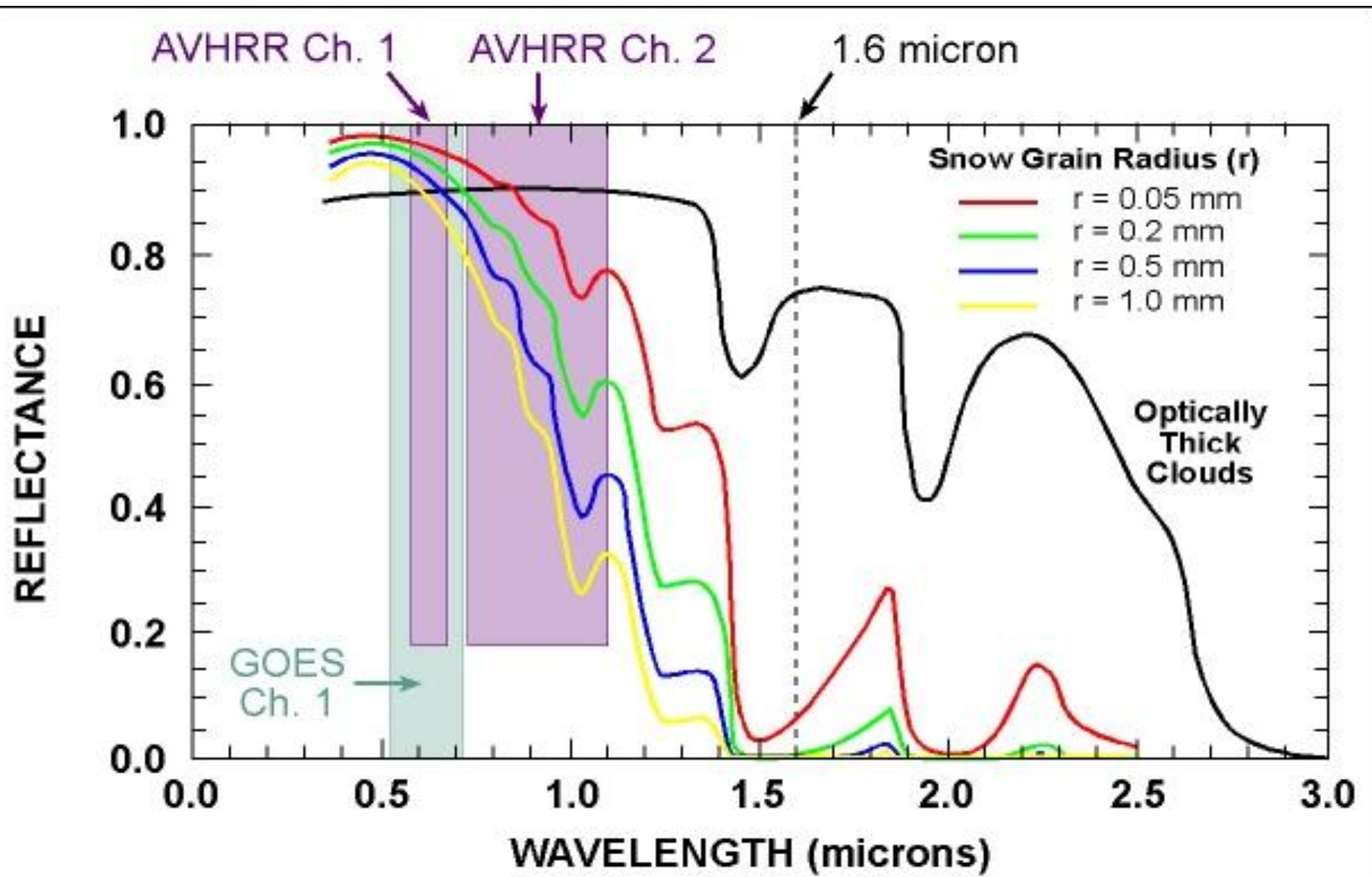 - Low resolution, 25 km grid cells
  - Signal is impacted by wet snow/snow metamorphism

Aqua AMSR-E Snow Water Equivalent over Northern Hemisphere
22 Mar 2006

NASA / NSIDC

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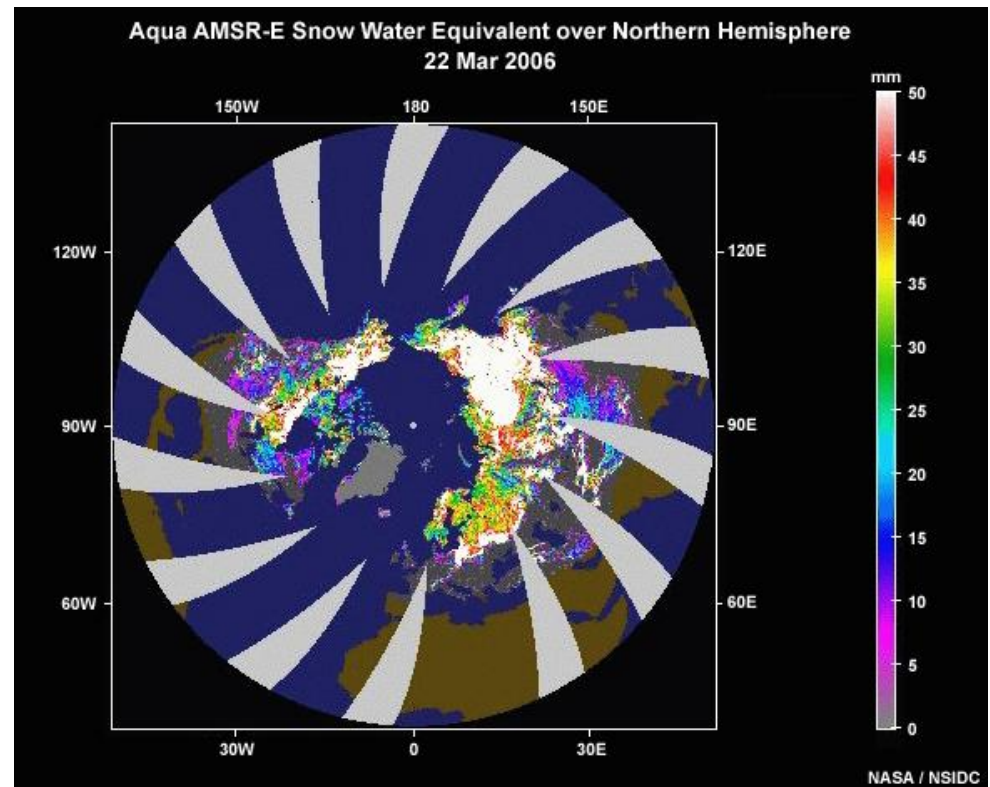
Passive Microwave Detection of Snow

- Microwave radiation from the soil and the snowpack is scattered by the snow grains

- The reduced brightness temperature detected by the sensor is a function of the snow depth and density

- For each 25 km² gridcell, a single brightness temperature is estimated

- Snow Depth Range
  - SSM/I: 0-40cm
  - AMSR-E: 0-100cm

- **SWE = C(T37H – T19H)**

Shallow/newer snowpack, smaller crystals

Deeper/older snowpack, larger snow grains

1-2 cm

©The COMET Program

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Optical Satellite Measurements of Snow Covered Area (SCA)

Remote Satellite Assessment of Snow Covered Area (SCA)

– <u>A</u>dvanced <u>V</u>ery <u>H</u>igh <u>R</u>esolution <u>R</u>adiometer (AVHRR)

- 1 km square pixel; can estimate sub-pixel snow coverage (0-100%)

- Daylight only; cannot see through clouds; no information on SWE

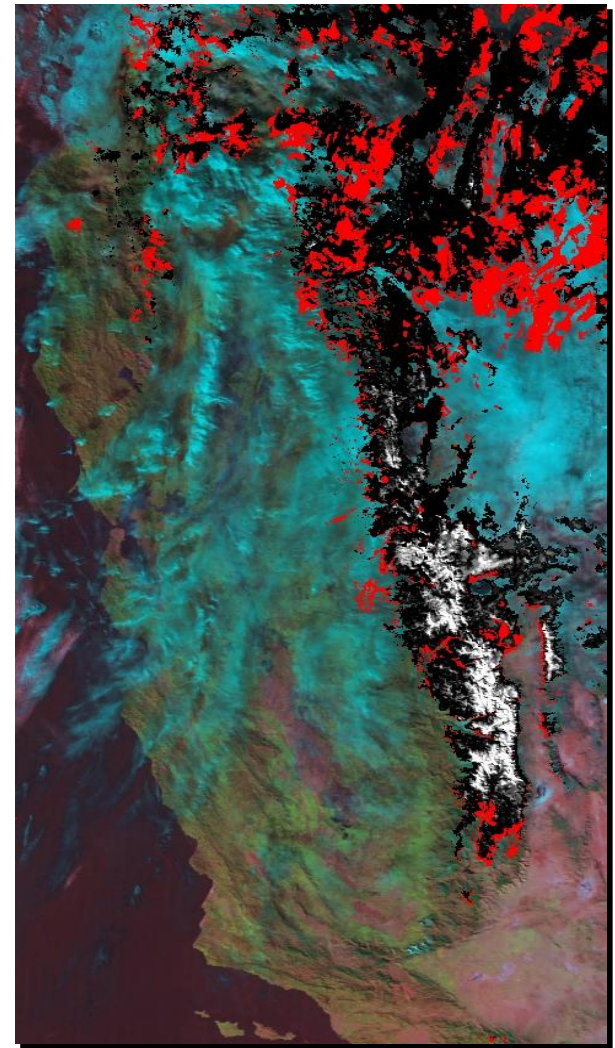- Requires extensive in-house processing

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snow data collection
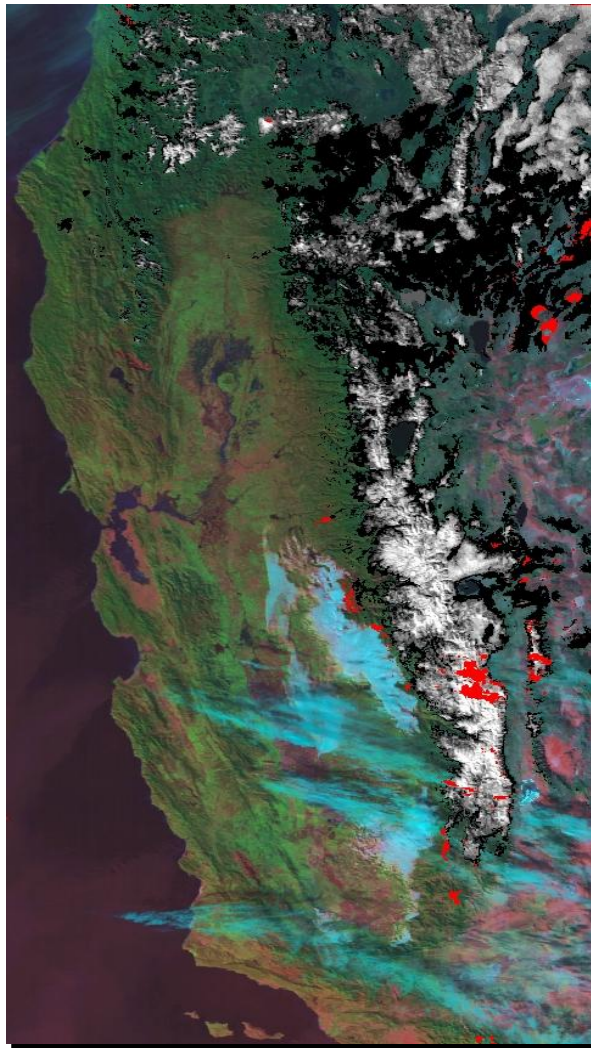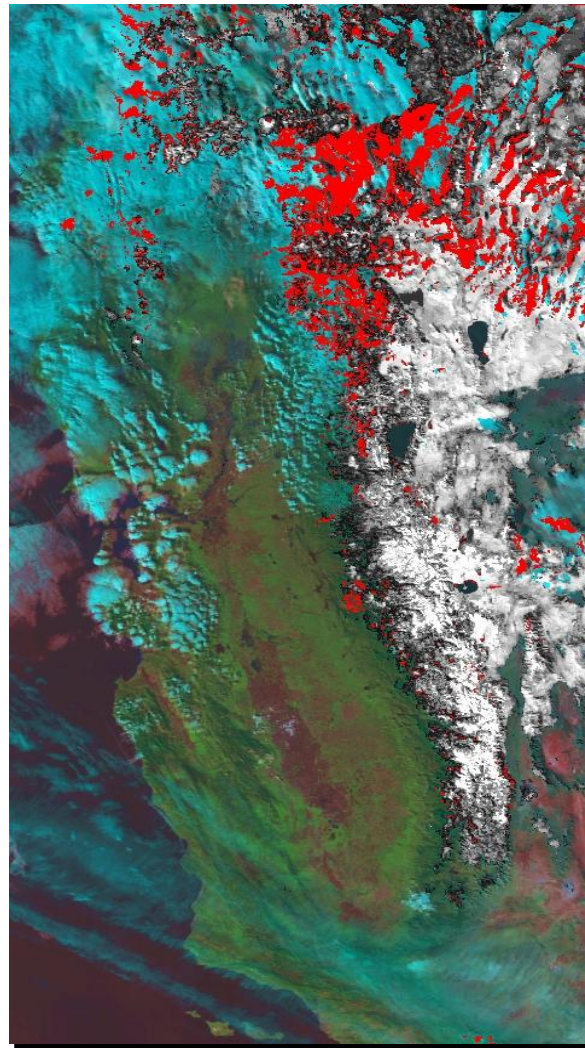
| 14 December 1996 | 23 December 1996 | 8 January 1997 |

Snow cover area (SCA) maps composited with color background, derived from NOAA AVHRR. SCA represented as gray shade from black to white. Clouds within maximum snow extent show as red.

Remote Satellite Assessment of Snow Covered Area (SCA)

– <u>Mod</u>erate Resolution <u>I</u>maging <u>S</u>pectroradiometer (MODIS)

- 500 m square pixel
- Daylight only, cannot see through clouds, no information on SWE
- Automatic classification
- http://nsidc.org/data/snowi/search.html

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snow data collection

Snow Covered Area, 25 Feb 2006
Kosovo

Legend
MODIS, 25 Feb 2006
- Snow
- Cloud
Watersheds
- Sinitca, Ibar
- Binacka Morava, Lepenac
- Beli Drim, Plavska
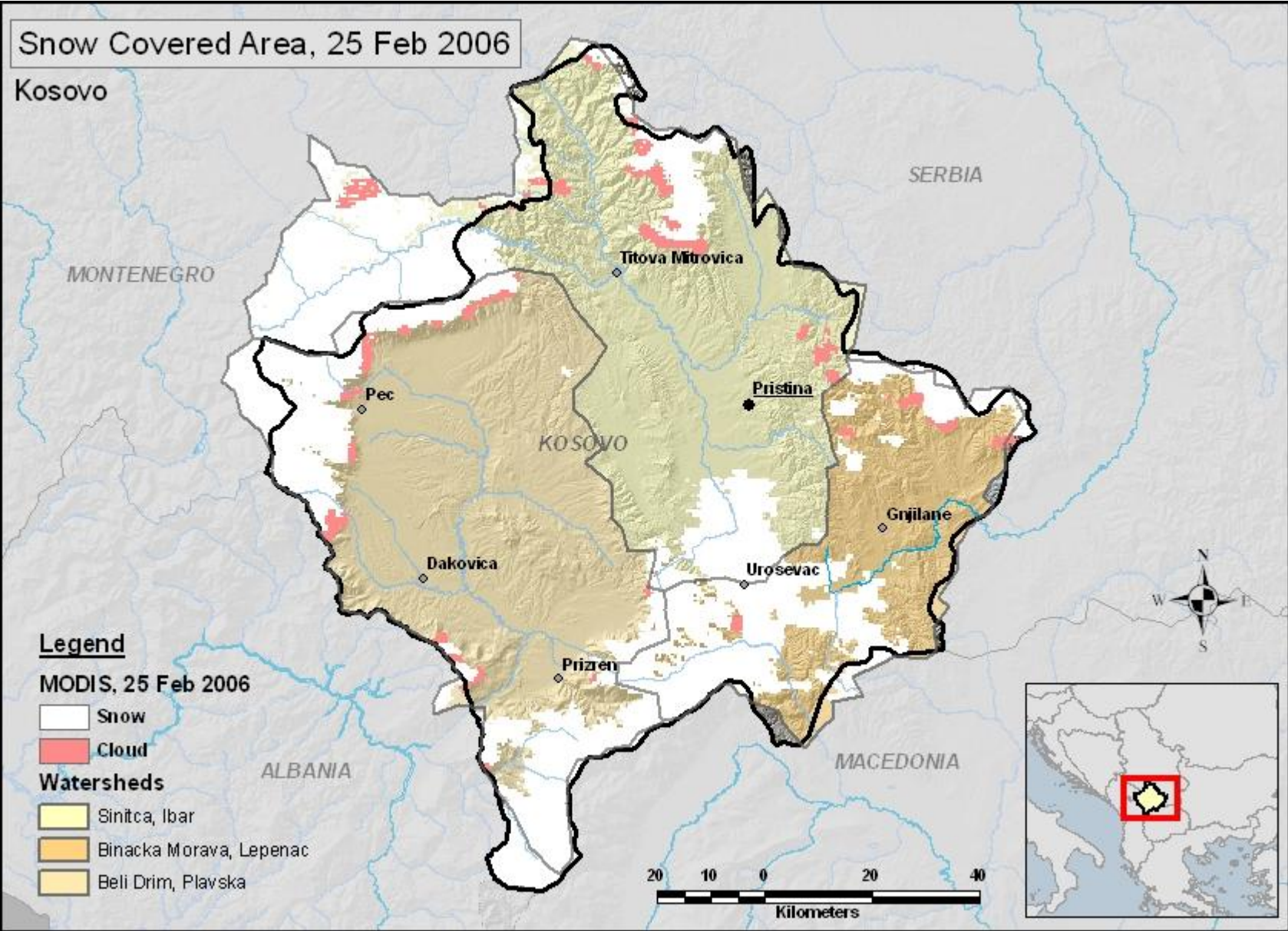
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Estimating Watershed SCA

SCA estimates are important where:

- No impact of elevation
- During the ablation period
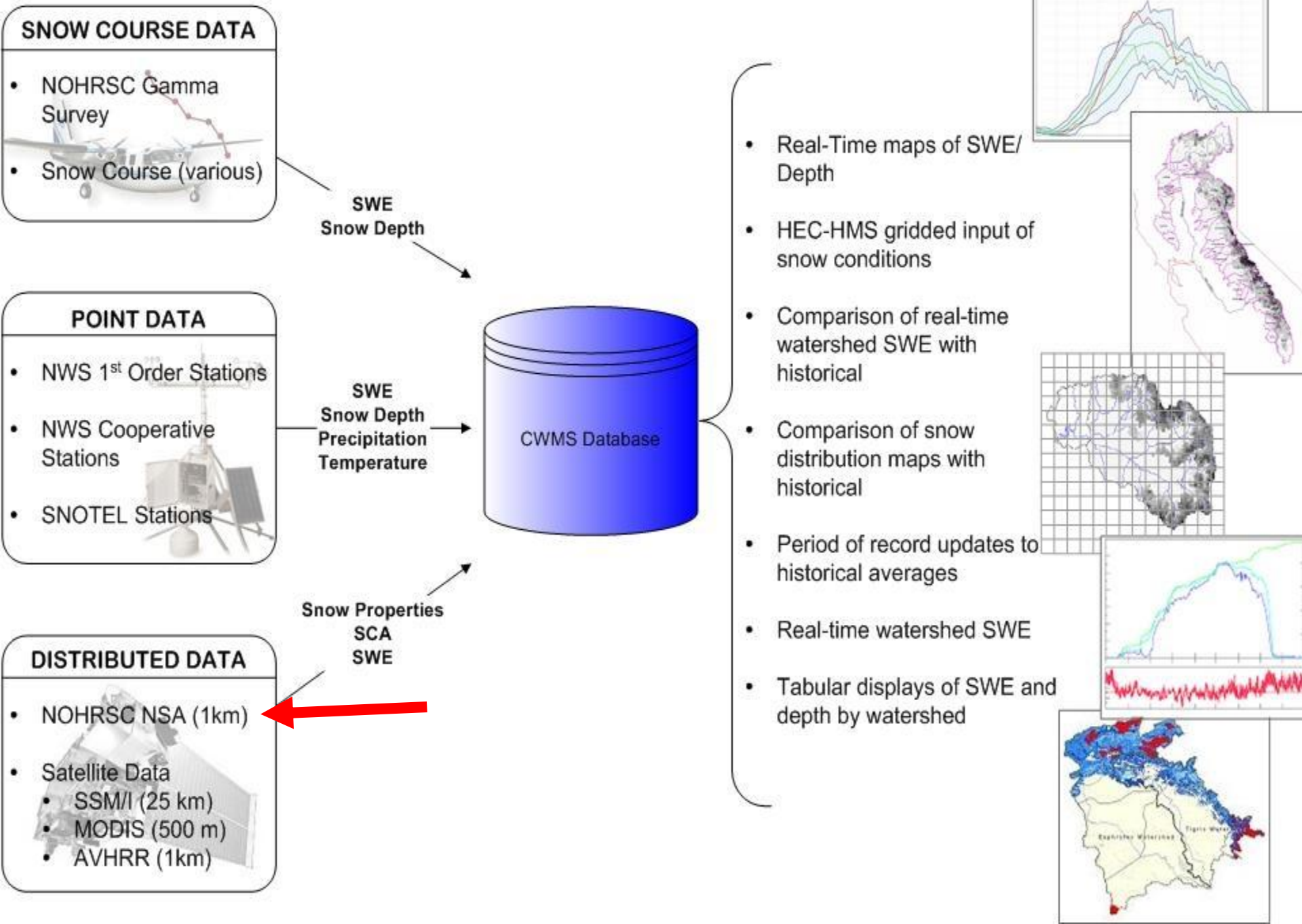- Snow exhibits spatial and temporal heterogeneity

Snow Distribution Great Plains - random tracks of episodic snowstorms with re-distribution by wind

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snow data collection

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Snow Depth

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NOAA's National Snow Analyses (NSA)

Multi-sensor Snow Observations

Snow Modeling and Data Assimilation

Snow Information Products

Ground

Airborne

Satellite

Numerical Weather Prediction Model Forcings

Gridded Snow Characteristics

U.S.

1-km^2

Hourly
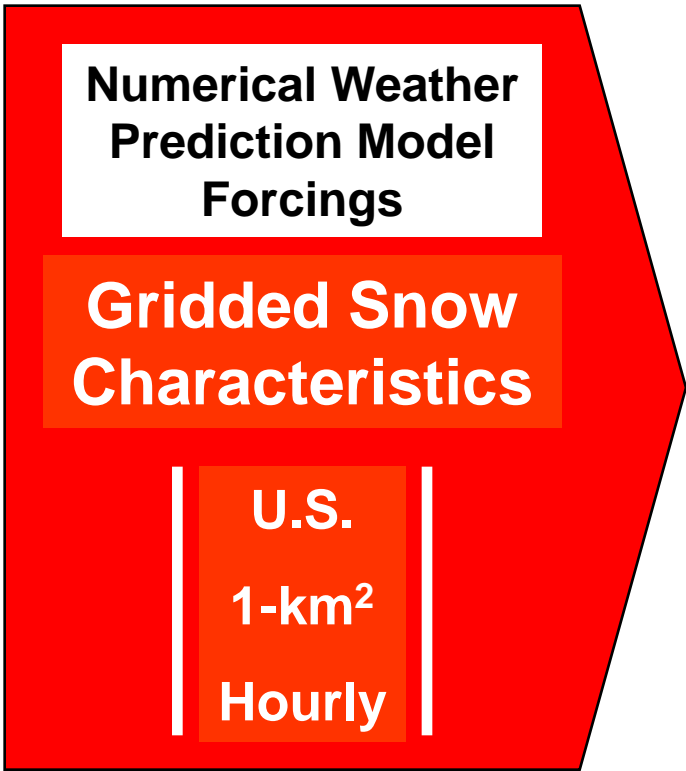
Data Products

Interactive Maps

Time Series Plots

Text Discussions

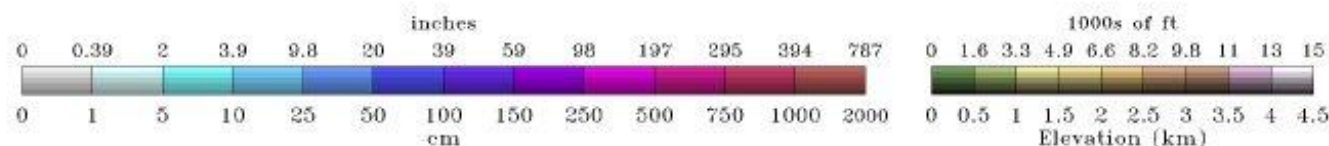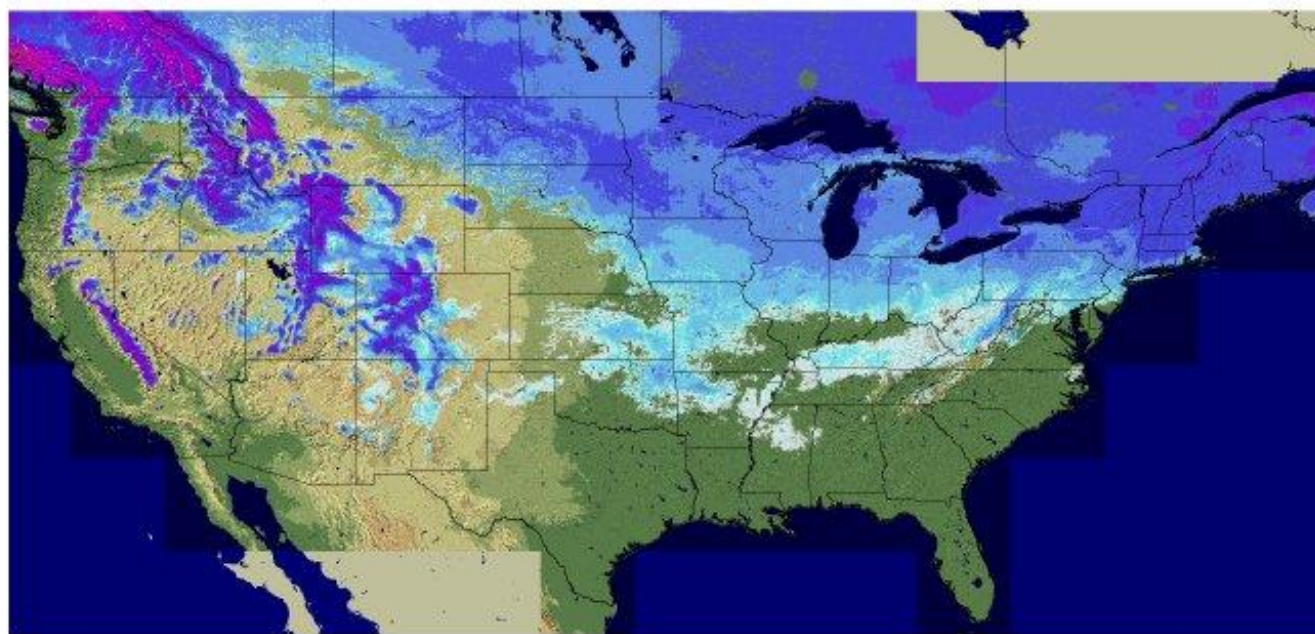US Army Corps
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Snow Modeling Framework

Hourly Input Gridded Data (1 km)

Temperature
Relative Humidity
Wind Speed
Solar Radiation
Atmos. Radiation
Precipitation
Precipitation Type

1

Snow Energy and Mass Balance Model

Blowing Snow Model

Radiative Transfer Model

2

Data Assimilation

Snow Observations

Snow Water Equivalent

Snow Depth

Snow Cover

Static Gridded Data (1 km)

Soils Properties
Land Use/Cover
Forest Properties

1

State Variables for Multiple Vertical Snow & Soil Layers
Snow Water Equivalent
Snow Depth
Snow Temperature
Liquid Water Content
Snow Sublimation
Snow Melt

3

NSA Product Generation
Interactive Maps
Digital Data
Discussions

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CONUS Snow Distribution 12/28/06-2/28/07 NOAA's NSA

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Estimating SWE

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Estimating Watershed SWE

SSM/I SWE Map
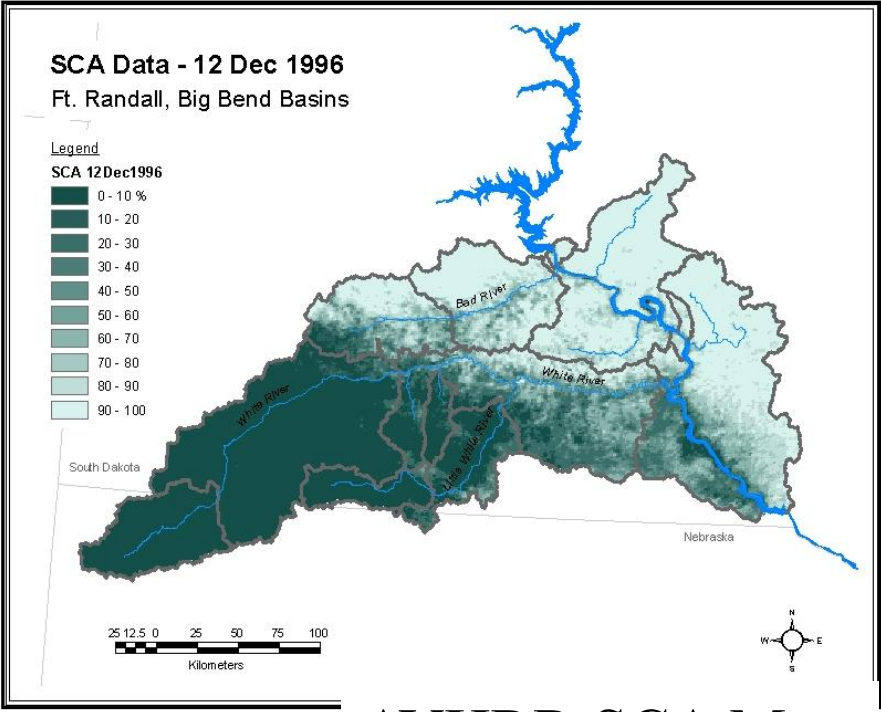
AVHRR SCA Map

Estimating Watershed SWE Volumes

•Point estimates of SWE interpolated using inverse distanced weighting
•Biased by SSM/I SWE
•Multiplied by AVHRR SCA

NWS with SSMI Bias x SCA - 18 Dec 1996
Ft. Randall, Big Bend Basins

Legend
NWS w/SSMI Bias x SCA
- 0 - 0.5 inches
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.64

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Estimating SWE

Oahe Basin

Legend: 15-Mar-97, 1-Mar-97

Categories: Survey, Survey X SCA, NWS Data, NWS X SCA, Survey + NWS, Survey + NWS X SCA, SSARR, SSARR X SCA

of Engineers

Estimating Watershed SWE: SSM/I

Amu Darya

Lake Superior Watershed SWE

TOTAL CRREL[01DEC1979-30APR2003] SWE TOTAL-AVER
TOTAL CRREL[01DEC1979-30APR2003] SWE TOTAL-AVER+SD
TOTAL CRREL[01DEC1979-30APR2003] SWE TOTAL-AVER-SD
TOTAL CRREL[01DEC1979-30APR2003] SWE TOTAL-MAX
TOTAL CRREL[01DEC1979-30APR2003] SWE TOTAL-MIN
TOTAL CRREL SWE TOTAL-2000-01

Snowmelt Forecasting Modeling

- Forecast snowmelt
  - Near term (1-5 days) based on met forecasts
  - Middle term (5-10 days) based on met forecasts
  - Seasonal – statistical or ensemble forecasts based on climatology or historical records

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Complete Energy Balance Snow Models
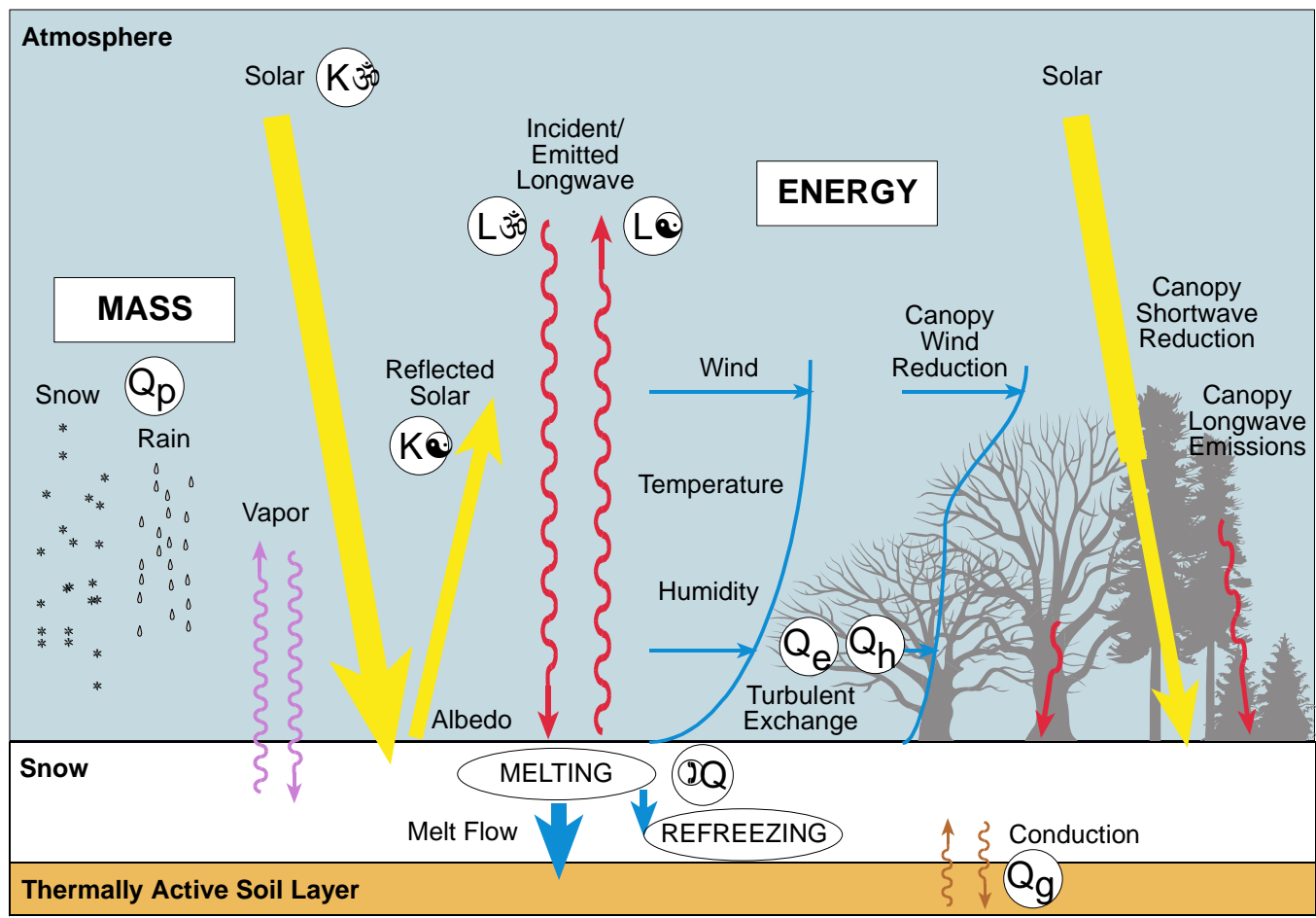
Temperature Index Snow Models
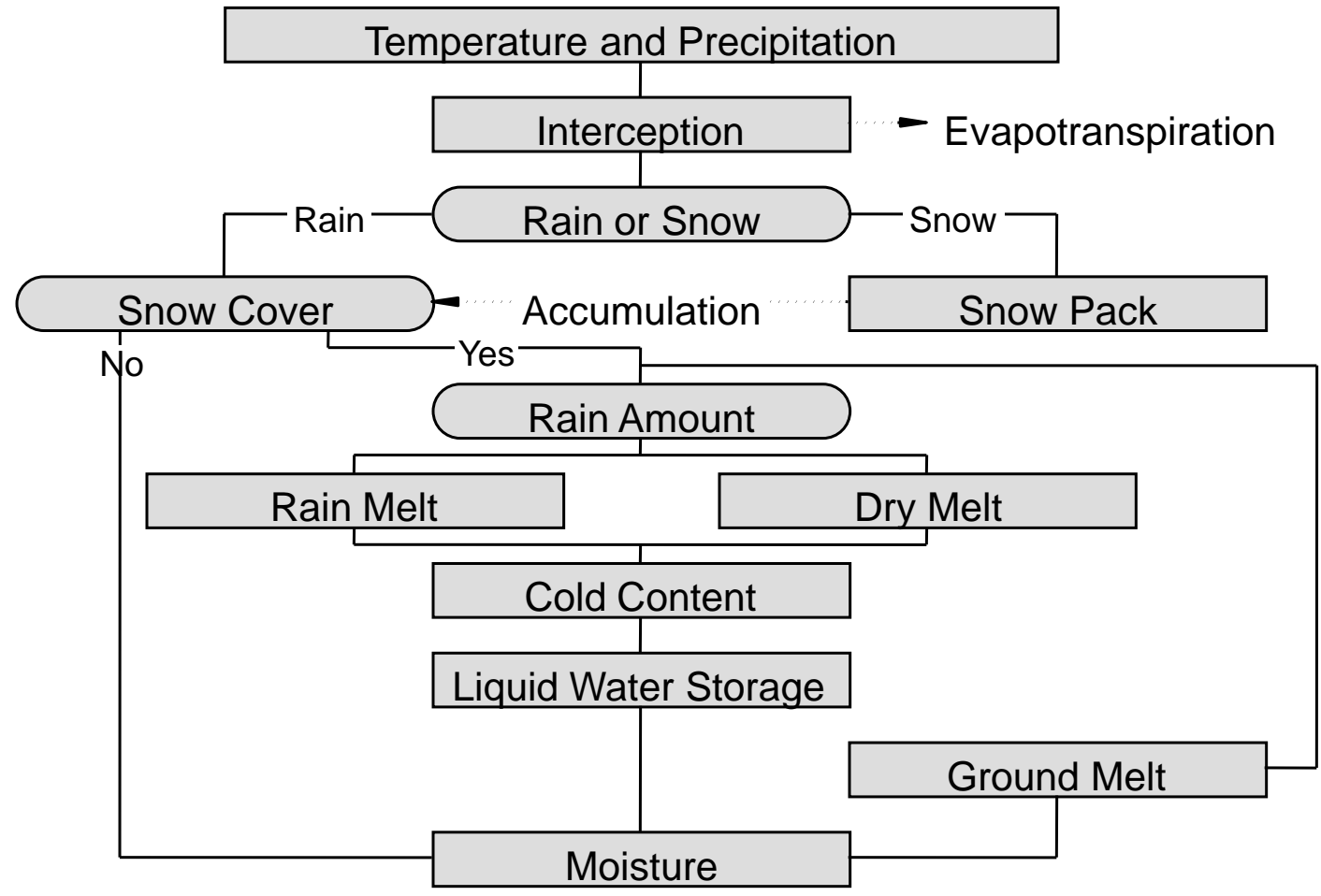
Snow Modeling

- Energy Balance
  - Wind
  - Temperature
  - Water Vapor
  - Radiation (Net)
  - Precipitation
- Detailed (layered) snow pack

- Temperature Index
  - Temperature
  - Precipitation
- Cold Content, Liquid water content
- One layer snow
- Calibration required

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Distributed Snow Modeling

Grid Net, 1km

Watersheds
Rivers
Grid Net

10   0   10   20 Kilometers
5   0   5   10 Miles
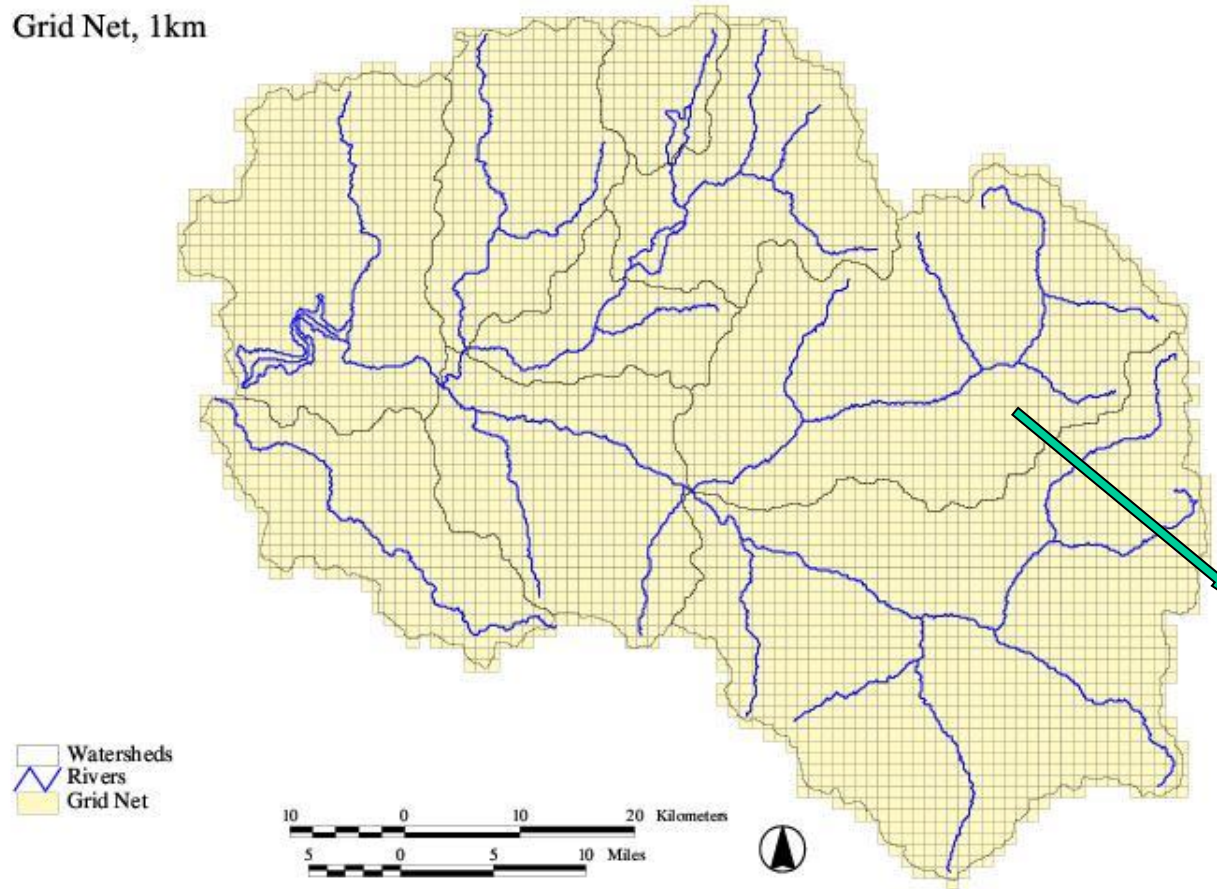
Snow model simulates snow conditions in each separate cell
Interpolate temperature and precipitation

Precipitation   Accumulated Temperature Index

Melt Factor

Cold Content
Liquid Water Content

Ground Melt

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snow modeling

Input

Computational Grid

Initial Conditions

Time

DSPM ↔ SSARR-Grid

Results

Time

Temperature
Precipitation

Watershed
Control
File

Cell
Parameter
File

Time Series Output:
Selected Grid Cells
Sub-Basin Results

Runoff
SWE
Cold Content
Liquid Water
ATICC
ATIMelt
Interception

Distributed Snow Process Model (DSPM)

U
o

Daly-010

HEC Hydrologic Modeling System HEC-HMS
http://www.hec.usace.army.mil/

modClark Conceptual Model

Grid Superimposed on Basin

Cell Discharges: Function of a Cell Area, Snowmelt/Rainfall, Infiltration, and Travel Time

Attenuation by Linear Reservoir

Basin Direct Runoff Hydrograph

Cell Outflow Hydrographs Lagged by Travel Time

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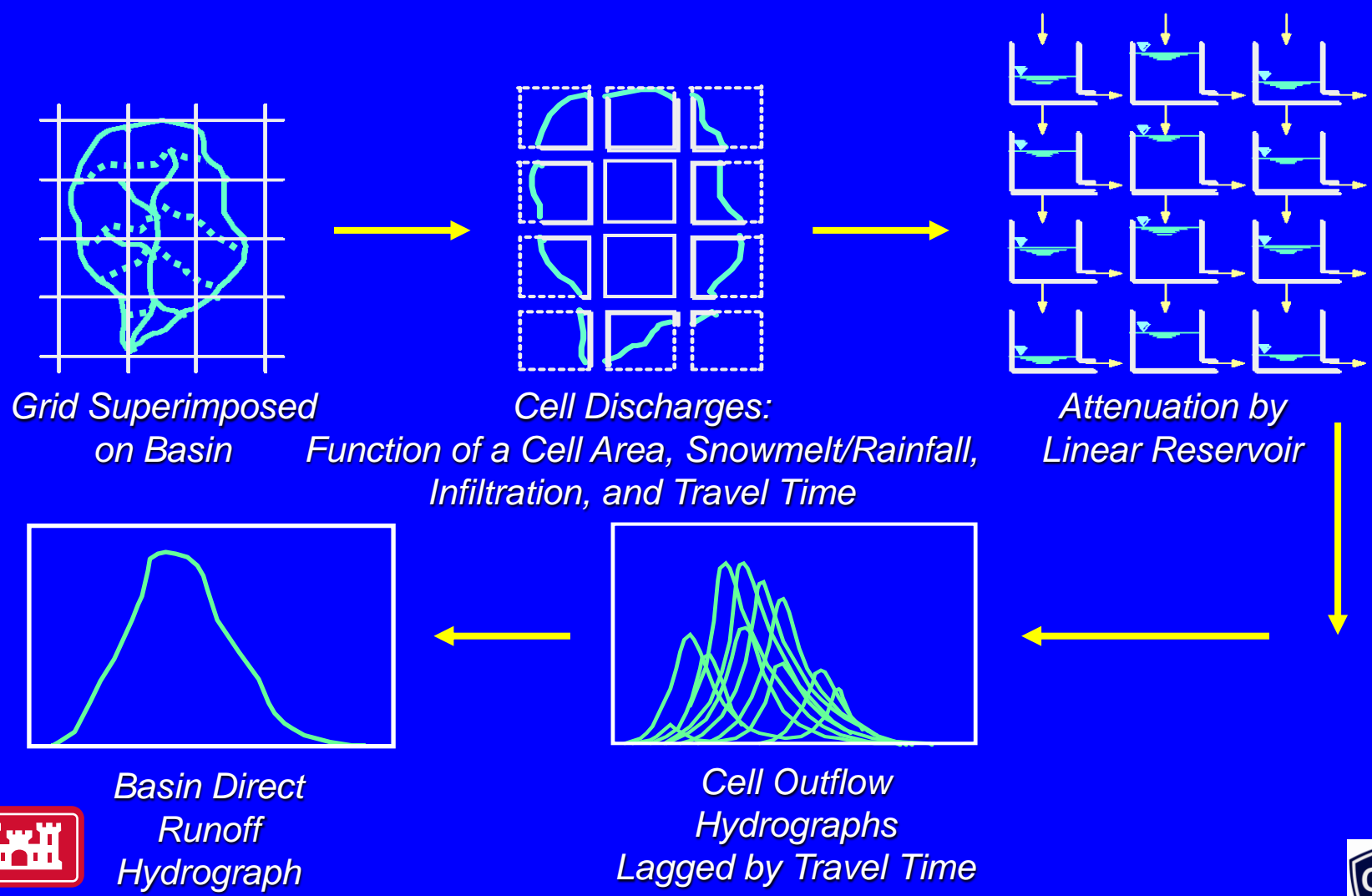
Distributed Hydrological Model

US Army Corps
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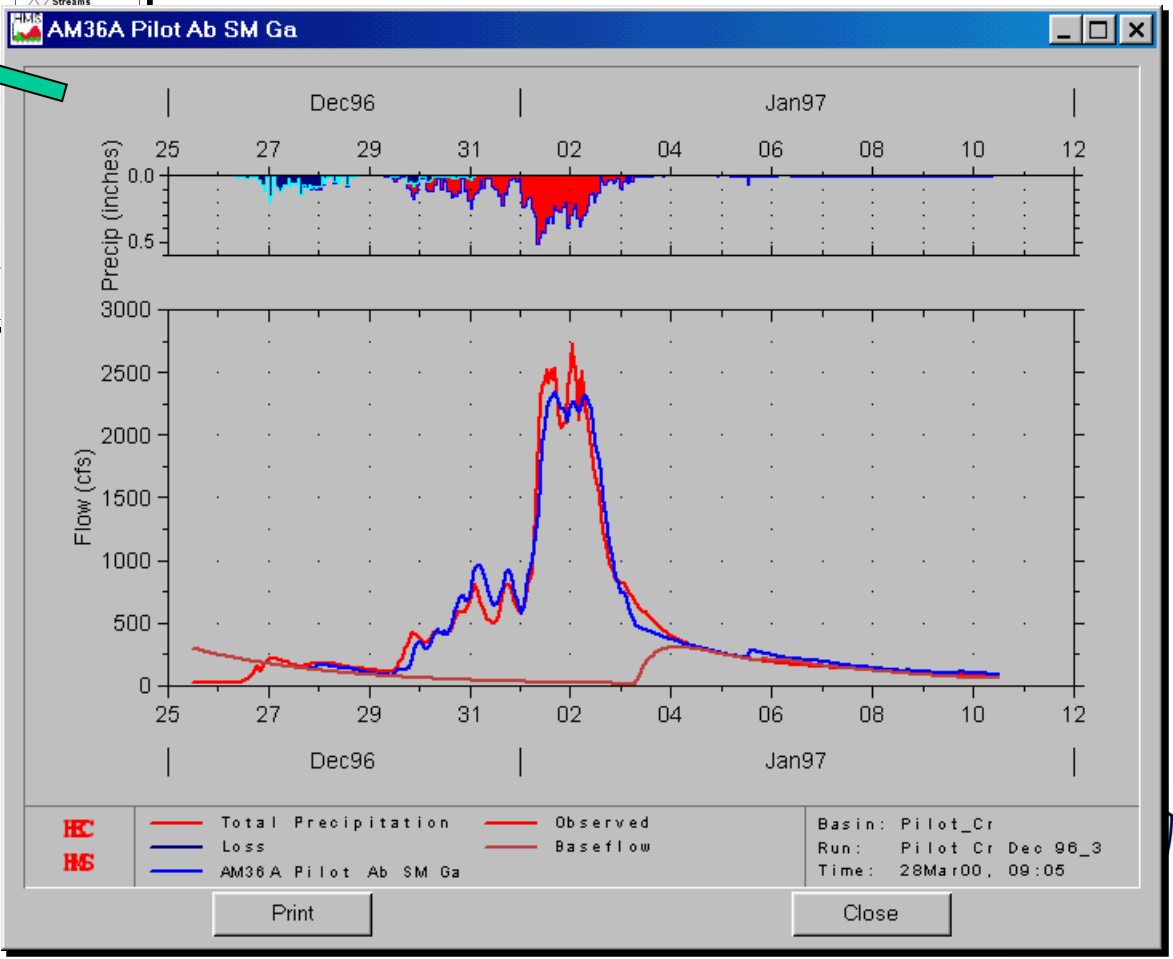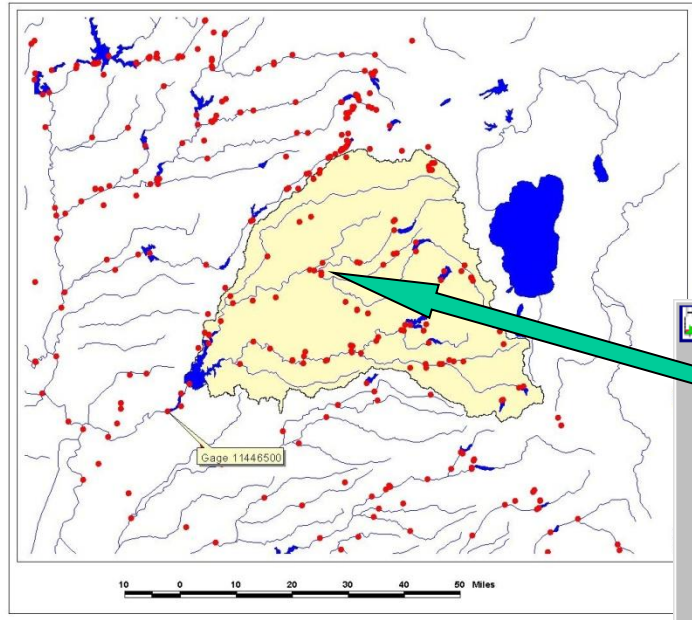
Operational Snow Hydrology Examples

- Chena River Basin, Fairbanks, AK
- Upper Helmand Watershed, Afghanistan
- Red River of the North, MN, ND
- Military Support

US Army Corps of Engineers

CRREL

Chena River Basin, Fairbanks, AK

Chena River Basin, Fairbanks, AK

Chena snow model
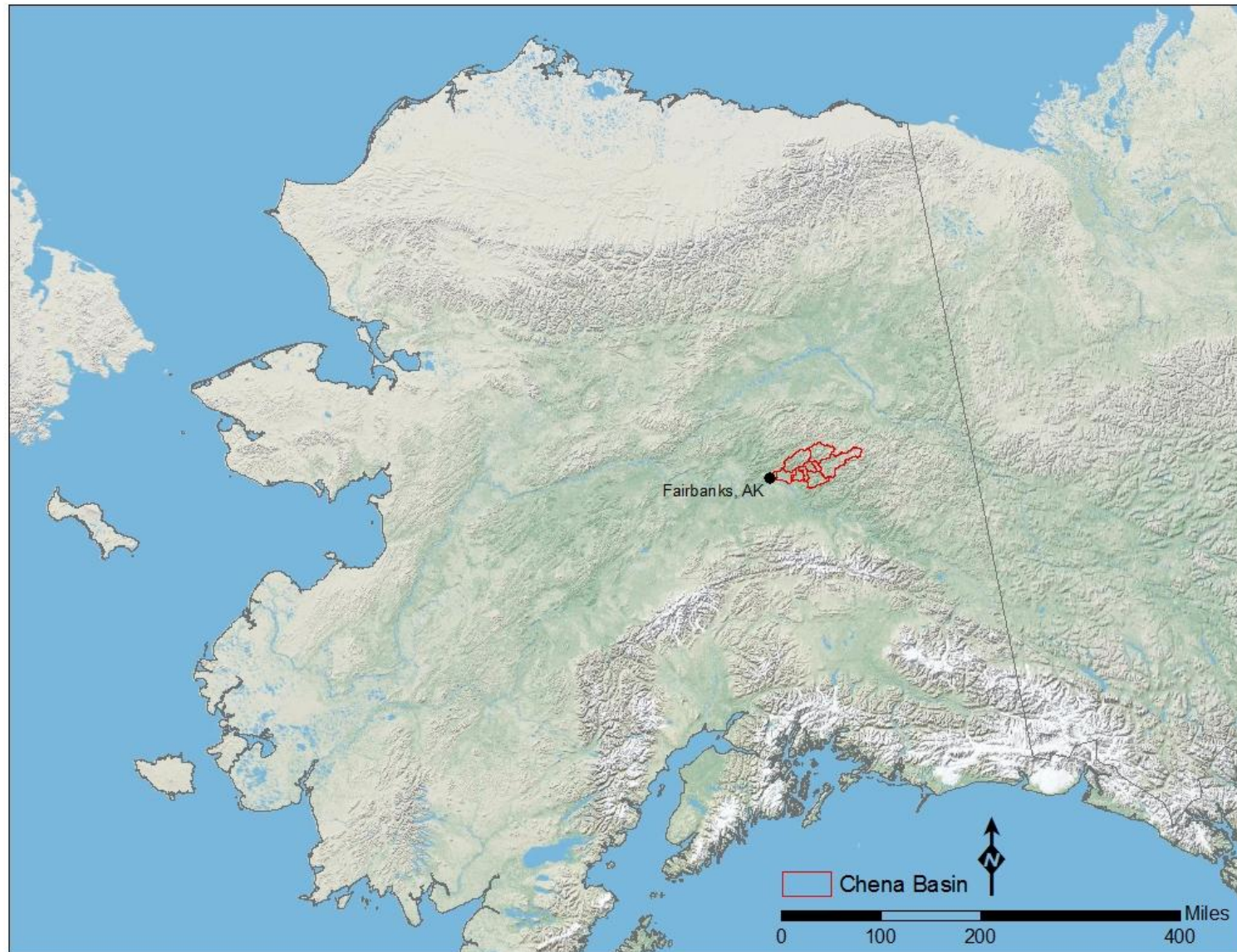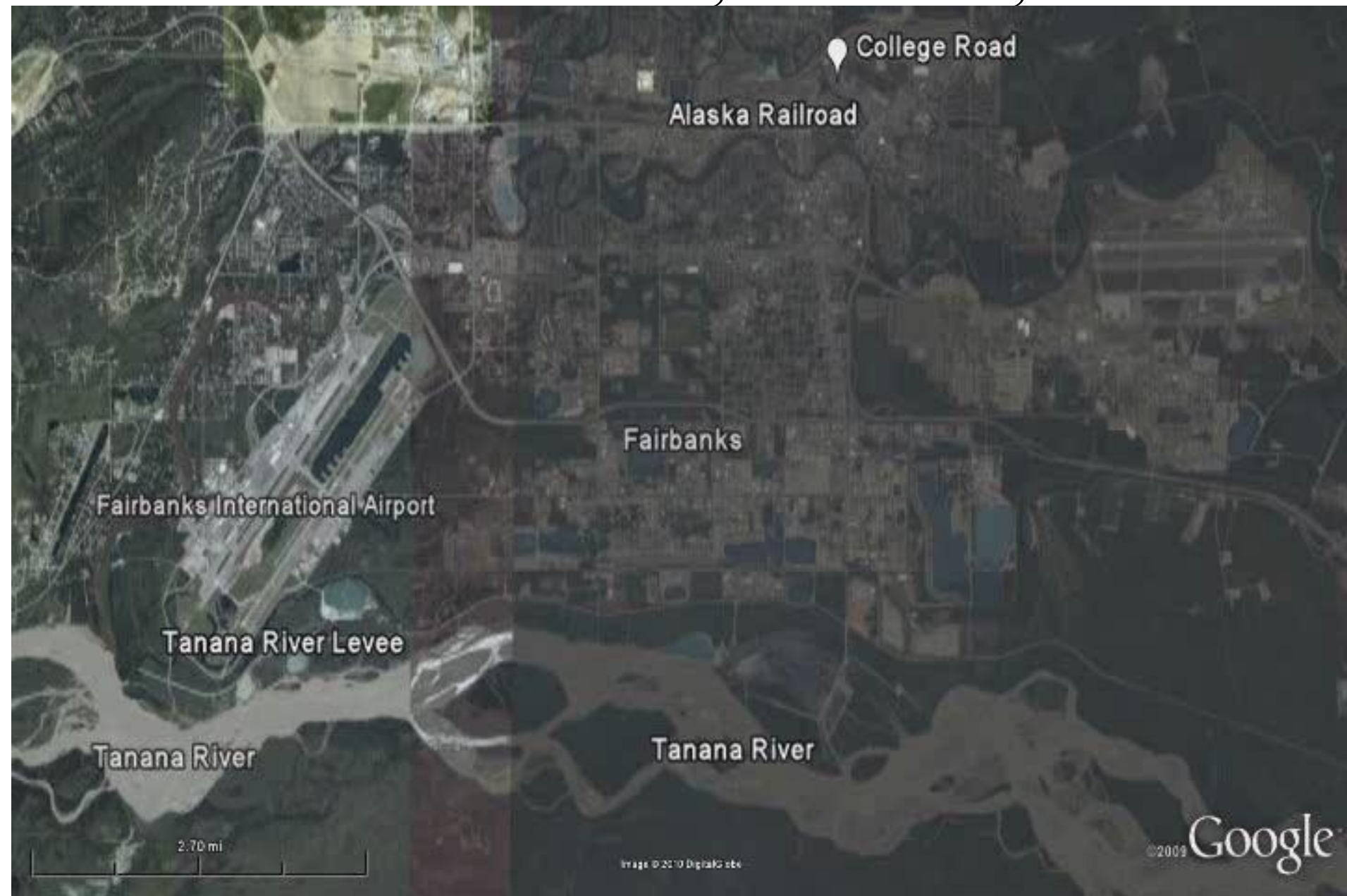
Geo-HMS

DEM

USGS National Elevation Data

-2 arc-second (approx 60 m) resolution

-Downloaded in GCS NAD83 projection

-Re-projected to NAD27 Albers

Fairbanks
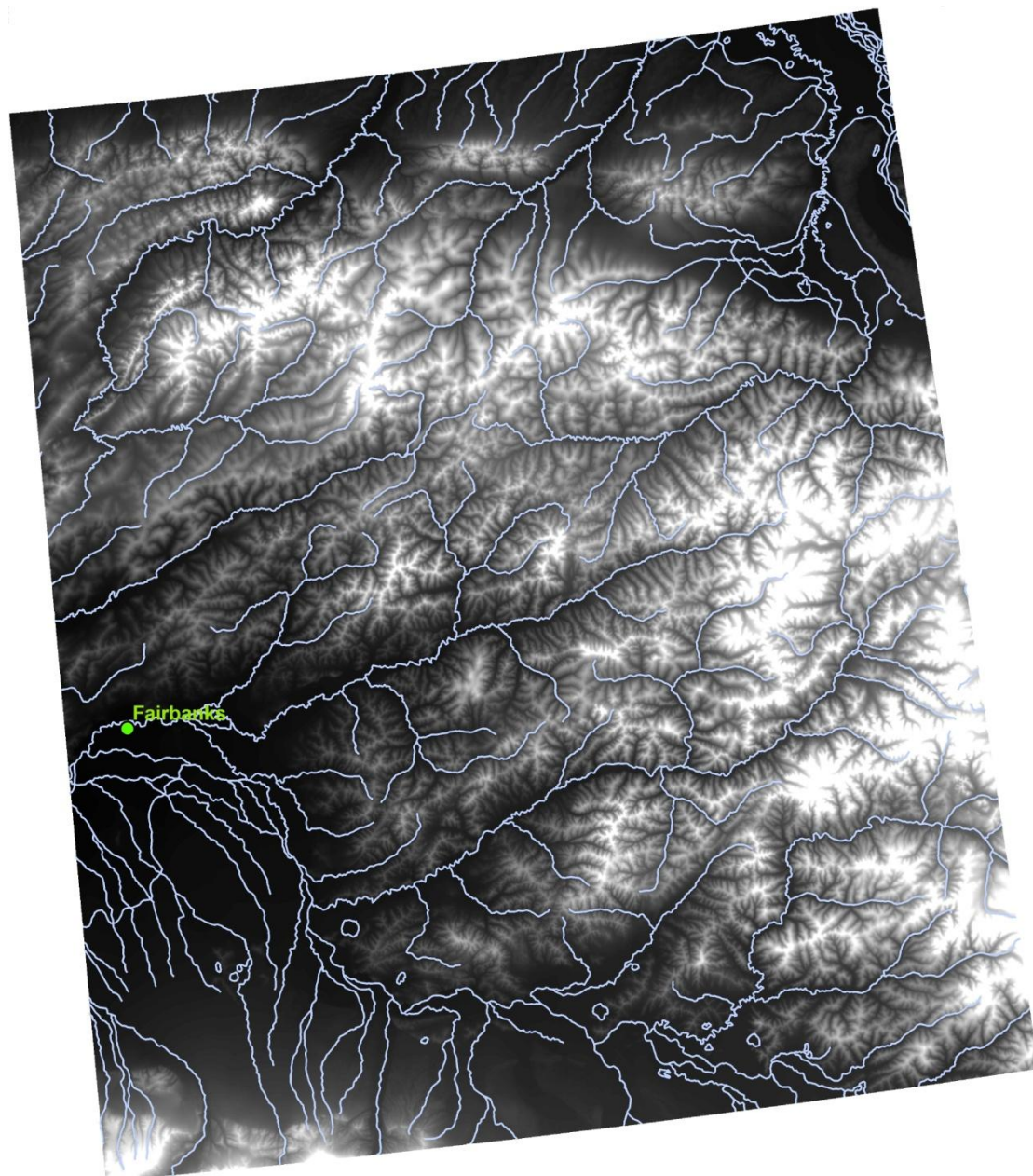
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Geo-HMS

Chena River Basin

-Area: 2053 mi^2

-Elevation range: 400 – 4800 ft
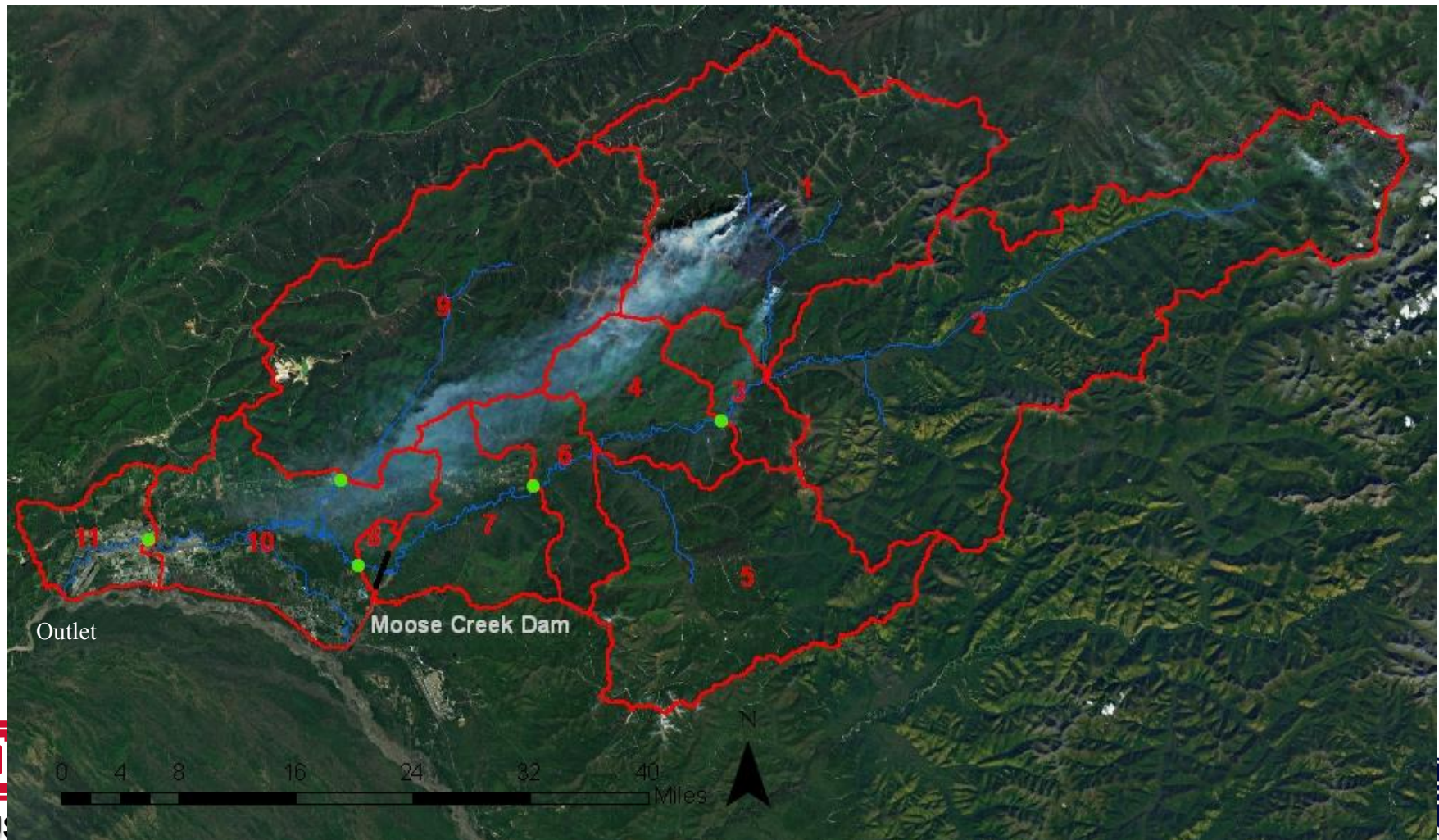
Basin Attributes

Subbasin	Description	Area (mi2)	Longest flow path length (mi)	Elevation at divide (ft)	Elevation at outlet (ft)	Slope (ft/ft)	Percent Impervious	Percent Permafrost
1	North Fork Chena River	345.9	34.3	4312.5	810.4	0.019	0%	53%
2	Middle Fork Chena River	539.4	57.3	4807.9	826.8	0.013	0%	54%
3	Two Rivers Local	49.2	16.2	2574.6	716.4	0.022	0%	42%
4	Above Hunts Creek Local	89.2	17.2	1906.8	659.5	0.014	0%	40%
5	South Fork Chena River	249.9	39.6	3096.6	675.9	0.012	0%	54%
6	Hunts Creek Local	69.4	13.4	2442.3	610.2	0.026	0%	45%
7	Above Moose Creek Dam Local	104.4	25.5	2094.1	481.7	0.012	1%	34%
8	Below Moose Creek Dam Local	7.4	2.1	521.7	475.7	0.004	0%	3%
9	Little Chena	372.1	40.2	2905.8	495.4	0.011	0%	39%
10	Upper Fairbanks Local	168.1	38.2	1312.2	446.2	0.004	20%	5%
11	Lower Fairbanks Local	58.0	14.3	1355.0	400.3	0.013	35%	4%

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Basin Attributes
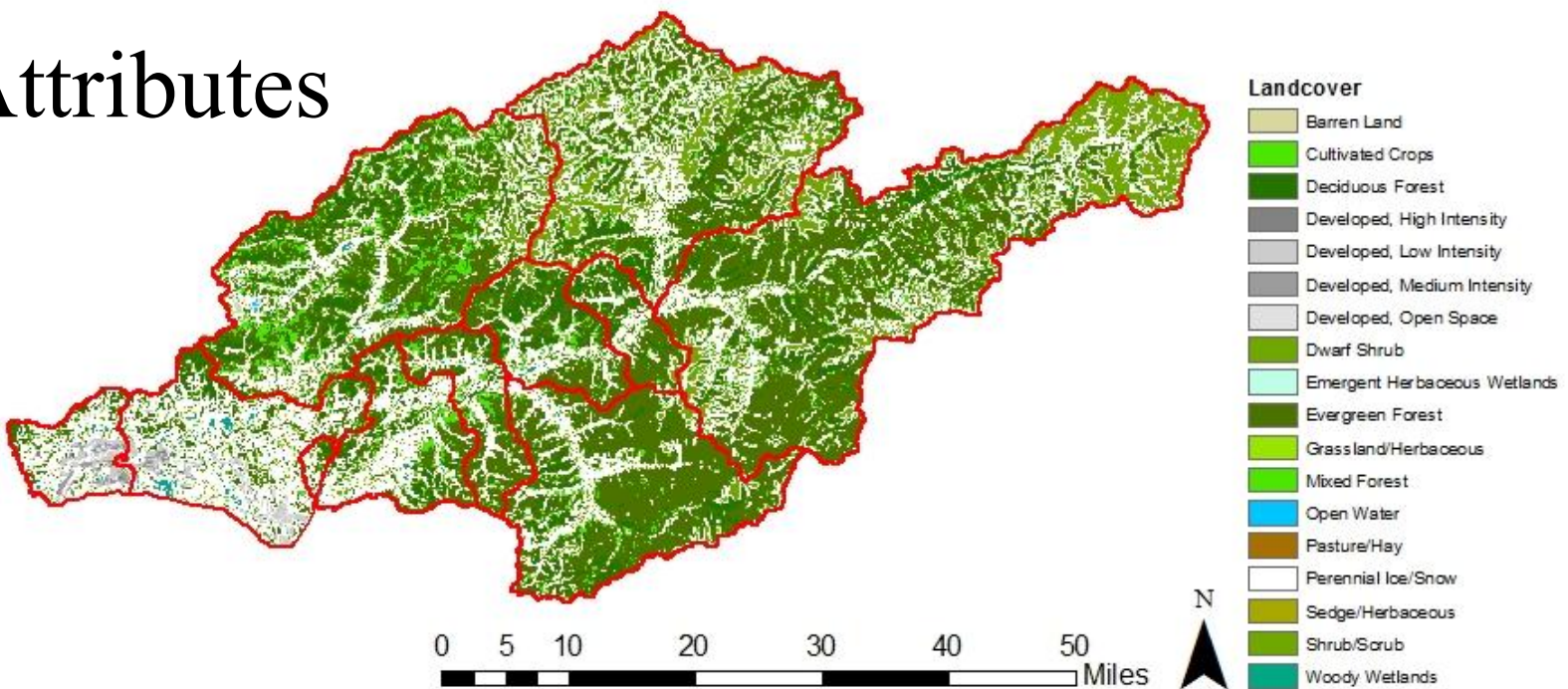
Landuse by subbasin (AK NLCD, 2001)

Landuse	1	2	3	4	5	6	7	8	9	10	11
Barren Land	1%	1%	0%	0%	0%	0%	0%	0%	1%	1%	1%
Cultivated Crops	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%
Deciduous Forest	13%	15%	42%	37%	21%	22%	31%	53%	25%	28%	25%
Developed, High Intensity	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
Developed, Low Intensity	0%	0%	0%	0%	0%	0%	0%	2%	0%	10%	23%
Developed, Medium Intensity	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
Developed, Open Space	0%	0%	0%	0%	0%	0%	1%	0%	0%	9%	9%
Dwarf Shrub	2%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Emergent Herbaceous Wetlands	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Evergreen Forest	50%	54%	36%	38%	61%	57%	36%	21%	45%	25%	17%
Mixed Forest	3%	3%	6%	11%	5%	10%	11%	9%	14%	4%	3%
Open Water	0%	0%	1%	1%	0%	1%	1%	2%	0%	2%	3%
Shrub/Scrub	27%	23%	11%	5%	7%	0%	3%	2%	7%	1%	1%
Woody Wetlands	2%	1%	4%	9%	4%	10%	15%	11%	6%	18%	10%
Other	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	1%

CRREL

Basin Attributes
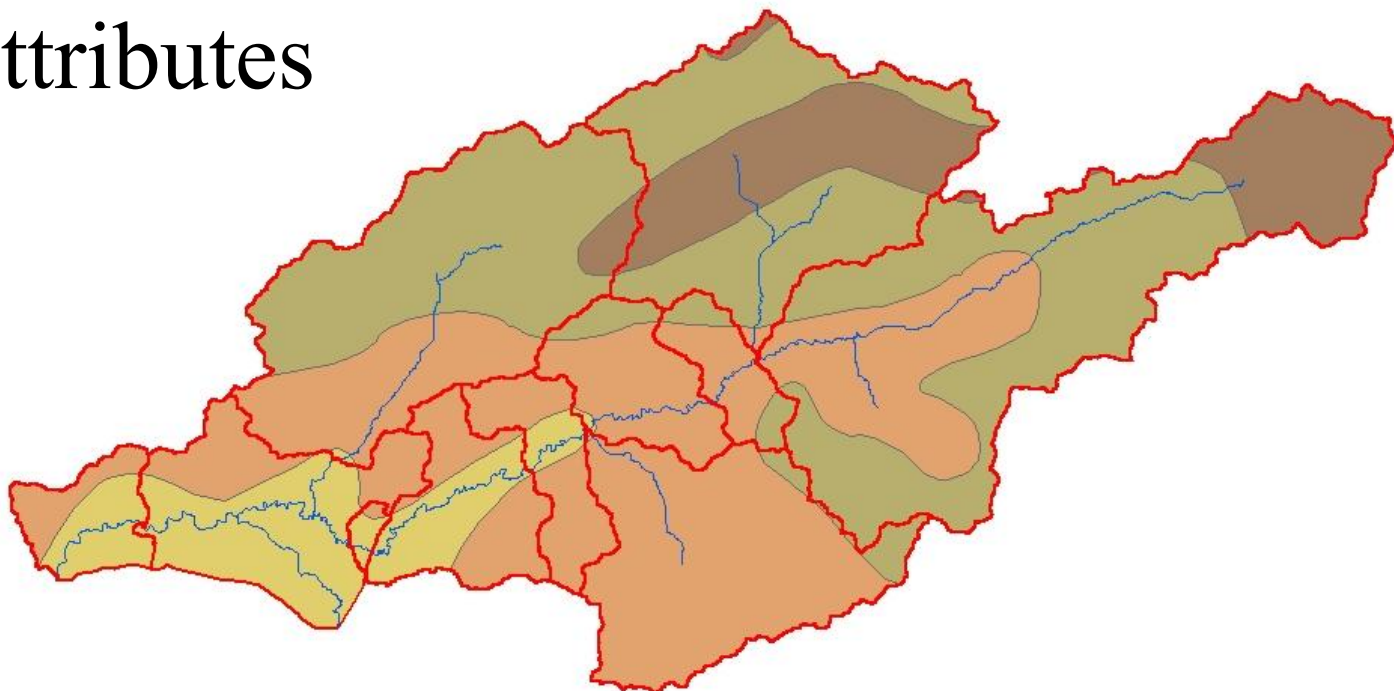
Soil Layers	Hydraulic Conductivity	Depth (in)	Notes
Fairbanks Organic Soil	High (0.5 – 20 in/hr)	10-30	Active layer, thaws immediately after snowmelt, saturation is function of time of year
Mineral Soil	Low (0.001 – 0.01 in/hr)	100+	Low permeability , long lag time

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Soil Data Sources
• STATSGO, 2002
• Bolton, Dynamic Modeling of the Hydrologic Processes in Areas of Discontinuous Permafrost, 2006
• Kane, Plot Measurements of Snowmelt Runoff for Varying Soil Conditions, 1984

CRREL

Chena snow model

HMS Project Setup
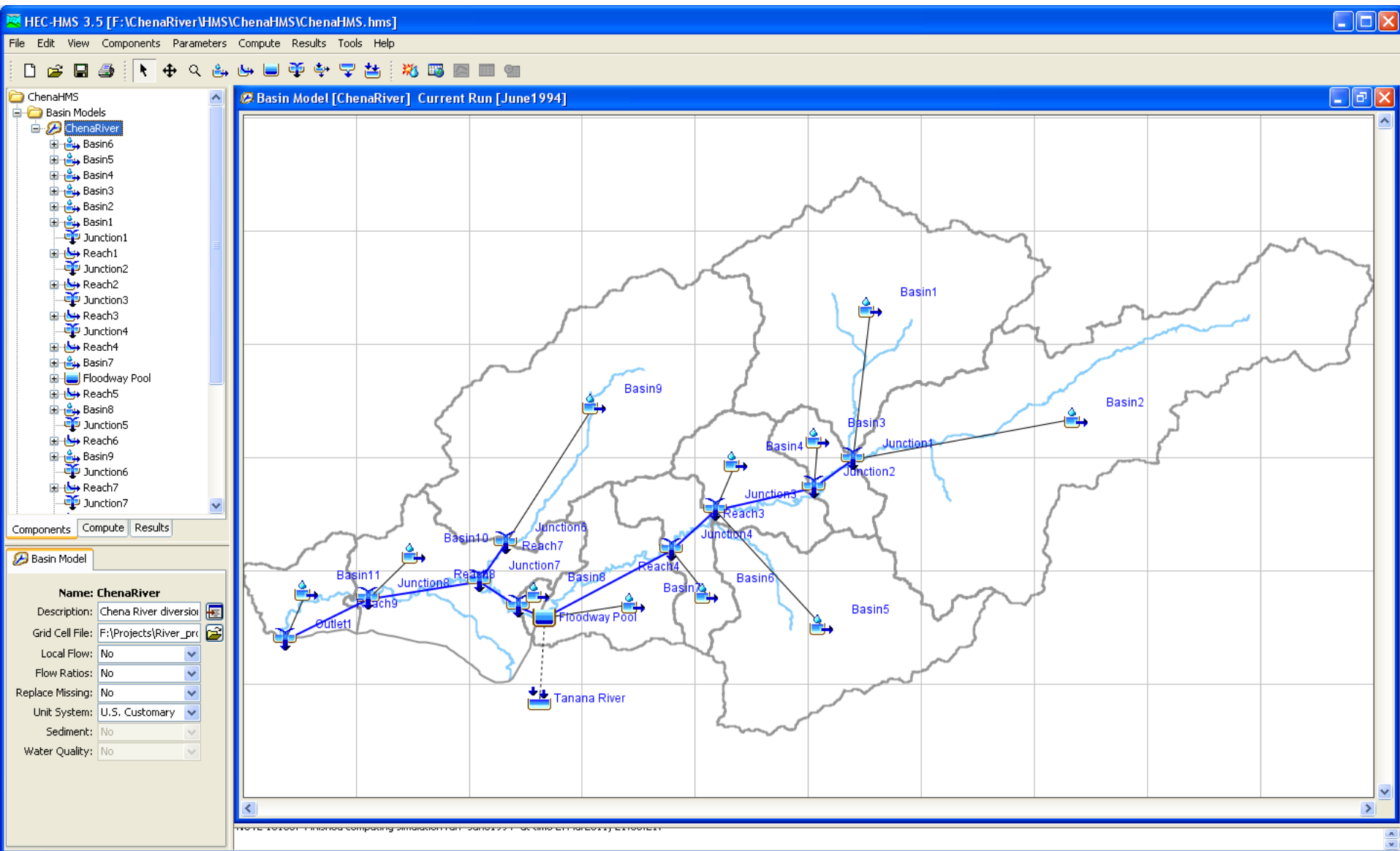
Basin Model

Transform Method: Clark Unit Hydrograph

$$t_c = 21.3 L_L A^{-0.1} S^{-0.2}$$

Baseflow Method: Recession $Q_t = Q_o K^t$

Loss Method: Soil Moisture Accounting

Routing Method: Muskingum-Cunge 8 point

Basin	t_c (hrs) (Williams)
1	10.2
2	17.7
3	5.7
4	6.3
5	13.5
6	4.4
7	9.4
8	1.3
9	13.2
10	16.6
11	5.6

Reach: Chena River at Two Rivers to Chena River below Hunts Creek
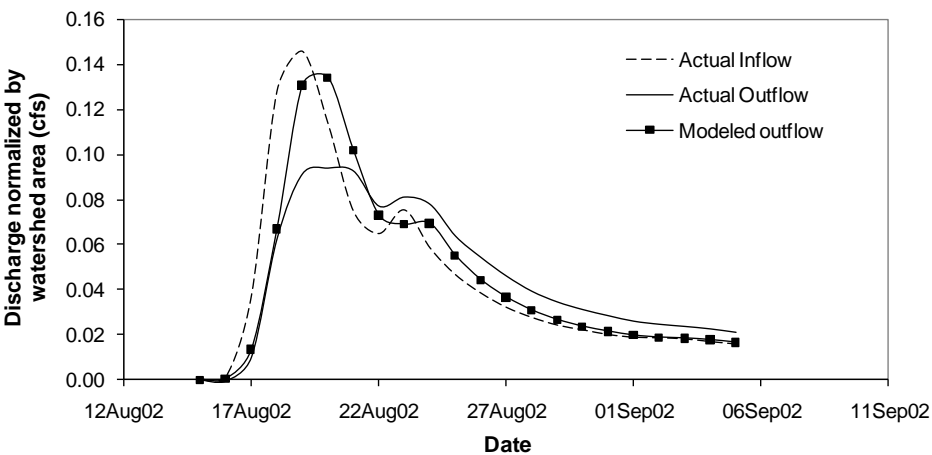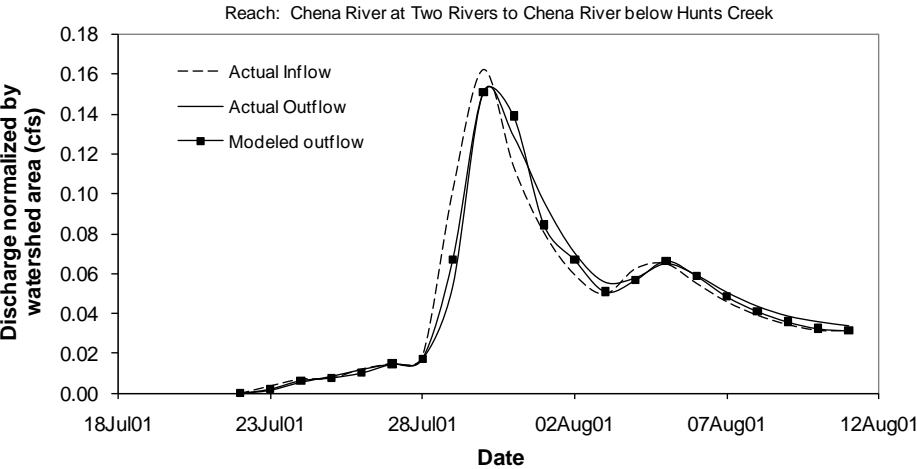
Meteorological Data
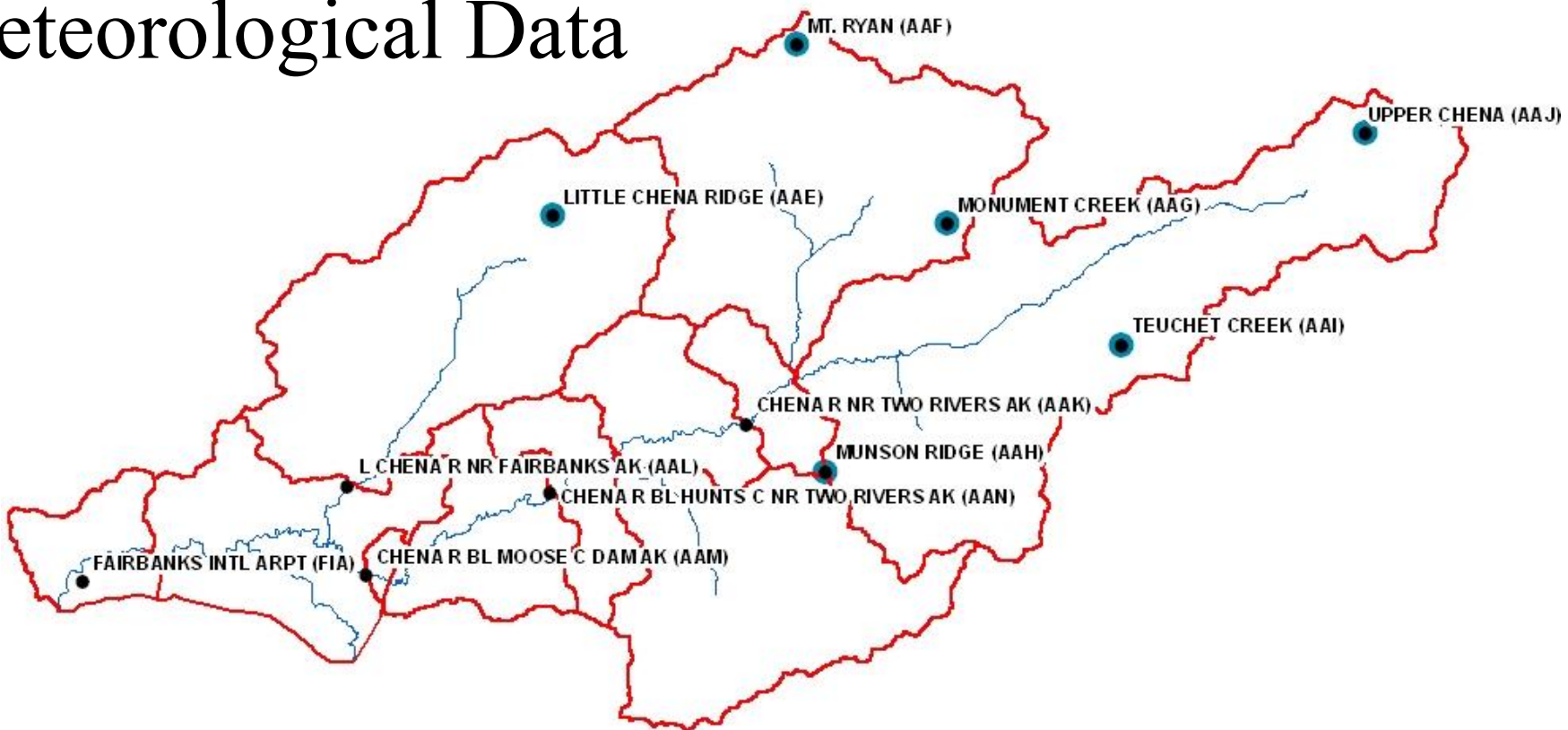
Gage	ID	Elev (ft)	Data Available	Date Start	Date End
Fairbanks International Airport	FIA	453	SWE, P, T	Oct-82	Jun-08
Little Chena Ridge	AAE	2000	SWE, P, T	Oct-81	Current
Mt Ryan	AAF	2800	SWE, P, T	Oct-81	Current
Monument Creek	AAG	1850	SWE, P, T	Oct-80	Current
Munson Ridge	AAH	3100	SWE, P, T	Oct-80	Current
Tuechet	AAI	1640	SWE, P, T	Oct-81	Current
Upper Chena	AAJ	2850	SWE, P, T	Oct-87	Current
Chena River at Two Rivers	AAK	720	Q, P, T	Oct-67	Current
Chena River bl Hunts Creek	AAN	638	Q, P, T	Oct-91	Sep-09
Chena River bl Moose Dam	AAM	490	Q, P, T	Aug-79	Oct-08
Little Chena River nr Fairbanks	AAL	460	Q, P, T	Aug-96	Current
Chena River at Fairbanks		423	Q	Aug-47	Current

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Model Calibration and Validation

- Calibration
  - 1994
  - 2008
  - 2009

- Validation
  - 1967
  - 1992
  - 1995

Model Calibration – June 2009
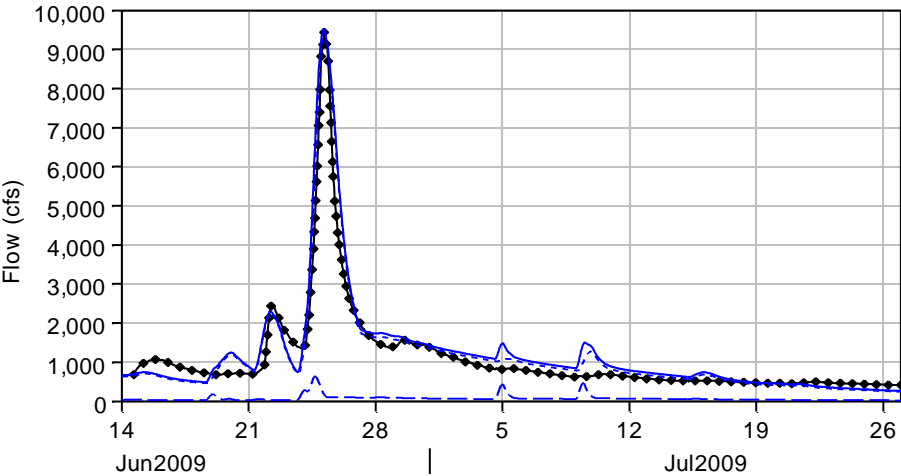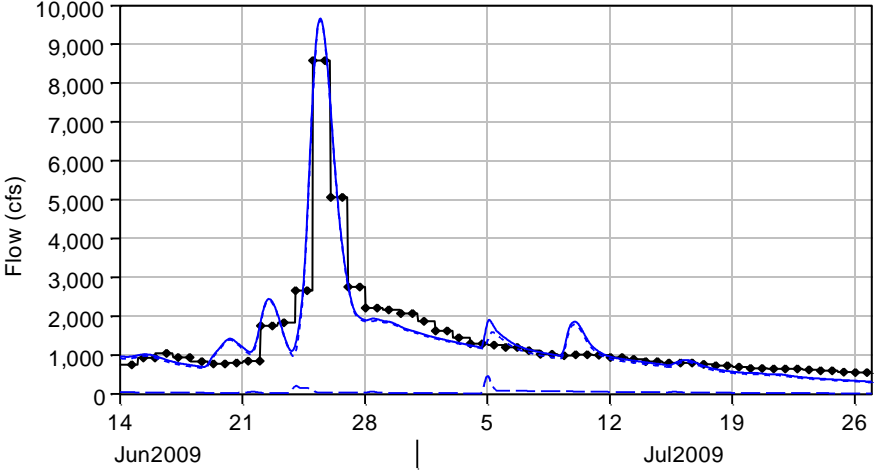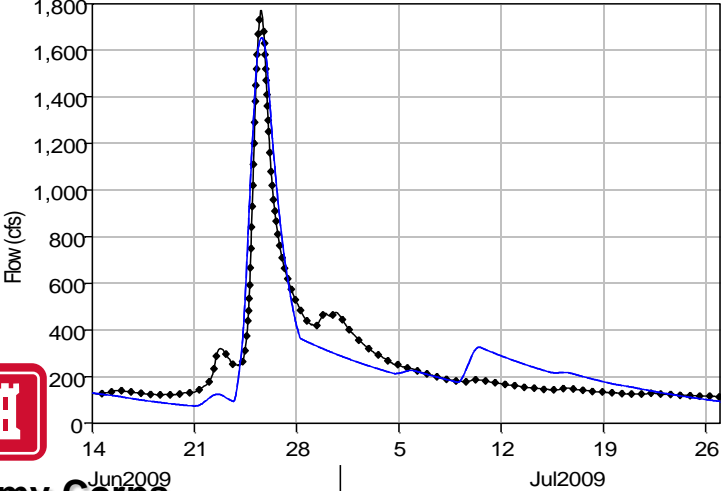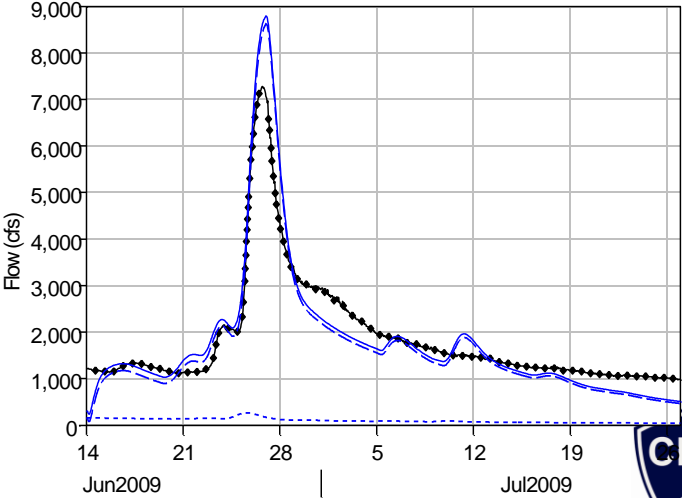
Operational Forecasting

Upper Helmand Basin, Afghanistan

Upper Helmand Watershed,
Afghanistan
Area: 47,000 km²

- Irrigation
- Water supply
- Flood reduction
- Power generation

Kajakai Watershed
Elevation (m)
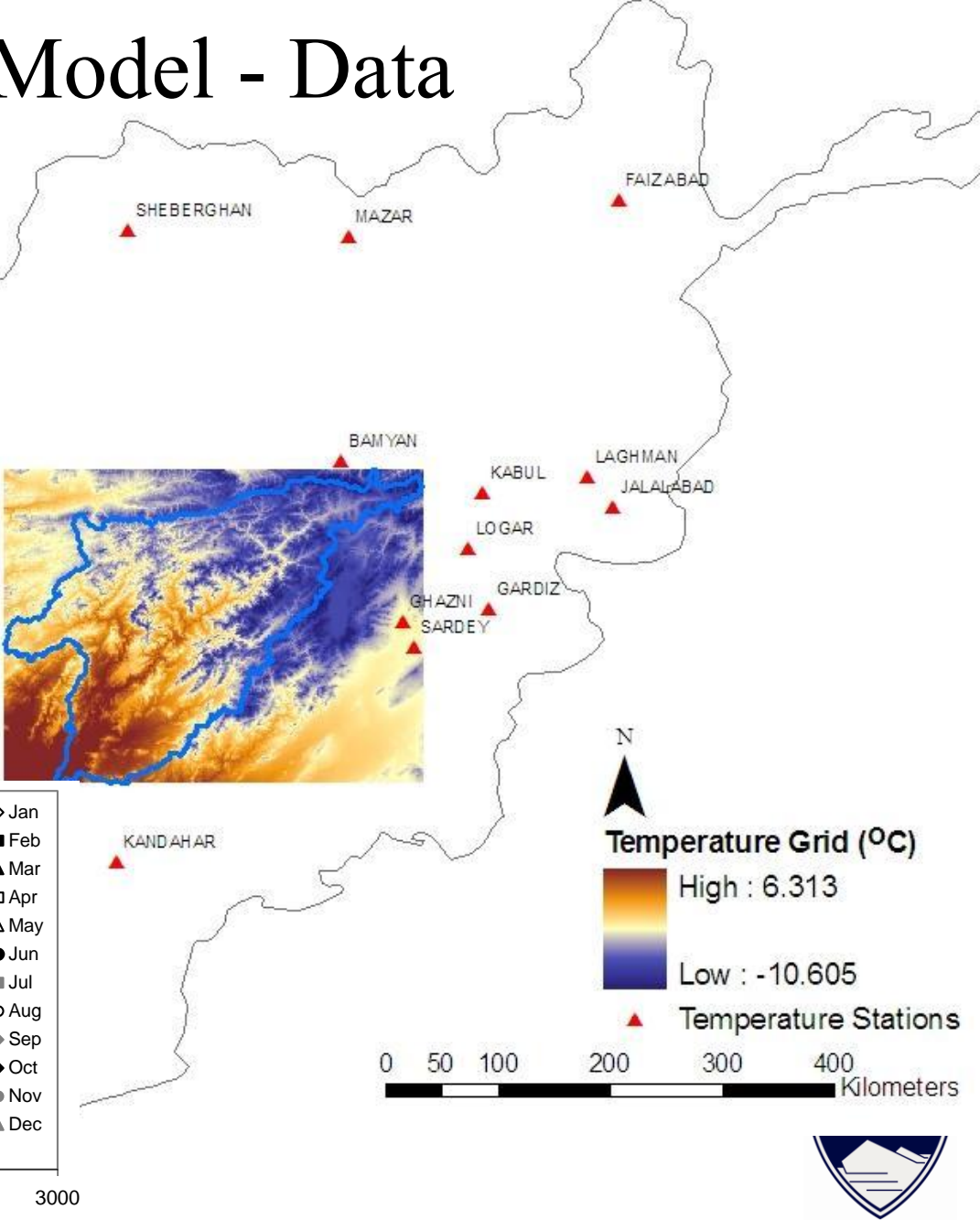High : 8311
Low : 0

**US Army Corps
of Engineers**

CRREL
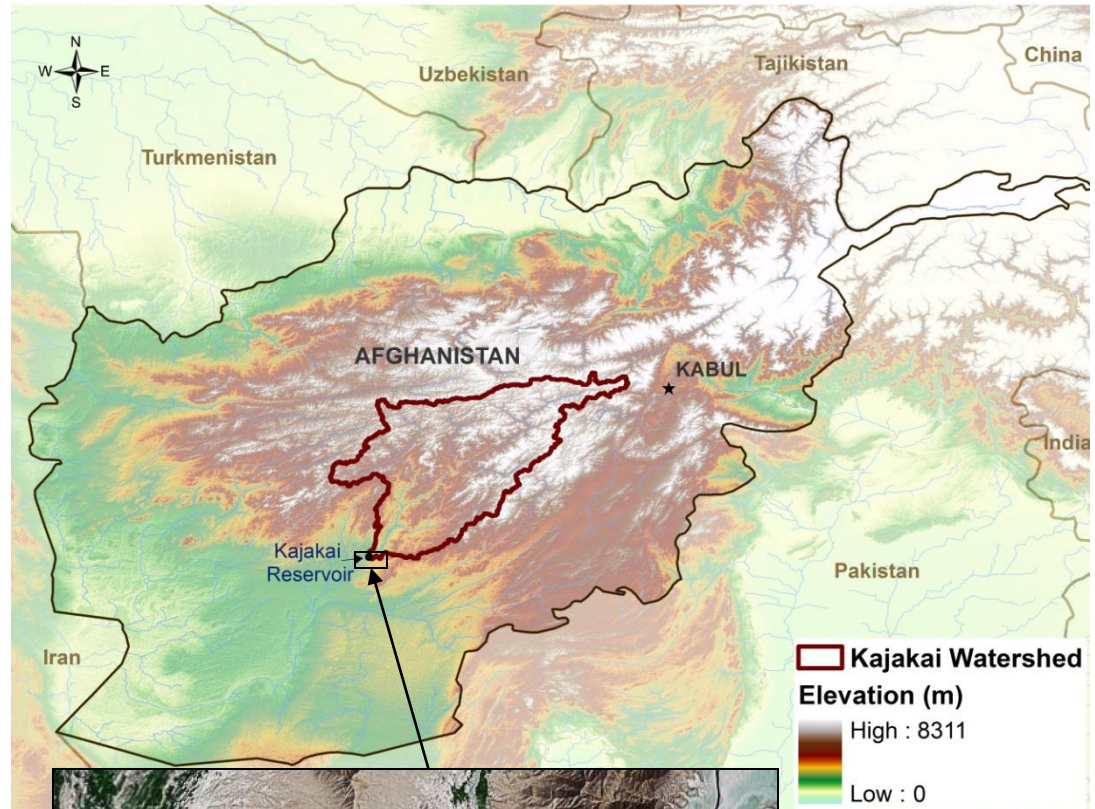
Study Location

- Spring runoff results from snowmelt and increased rainfall
- Arid country
- Limited data sources
- Floods/Droughts occur with little warning

Snow Hydrology Model

- Hydrologic Model
  - Distributed 1 km
  - Temperature index snow model
  - HEC-HMS
- 6 winter seasons
  - 01 OCT – 30 JUN
  - 2004 – 2009
- Model Input
  - Temperature
  - Precipitation

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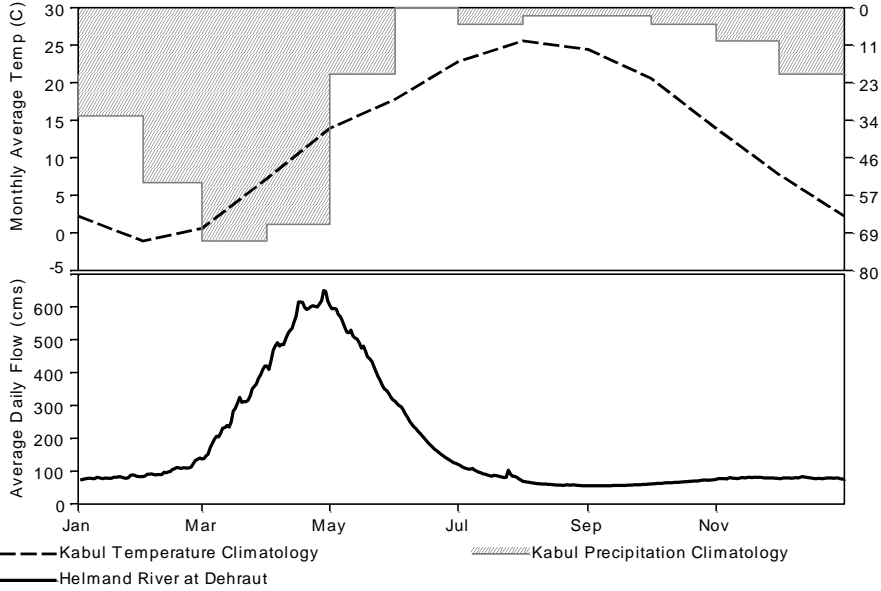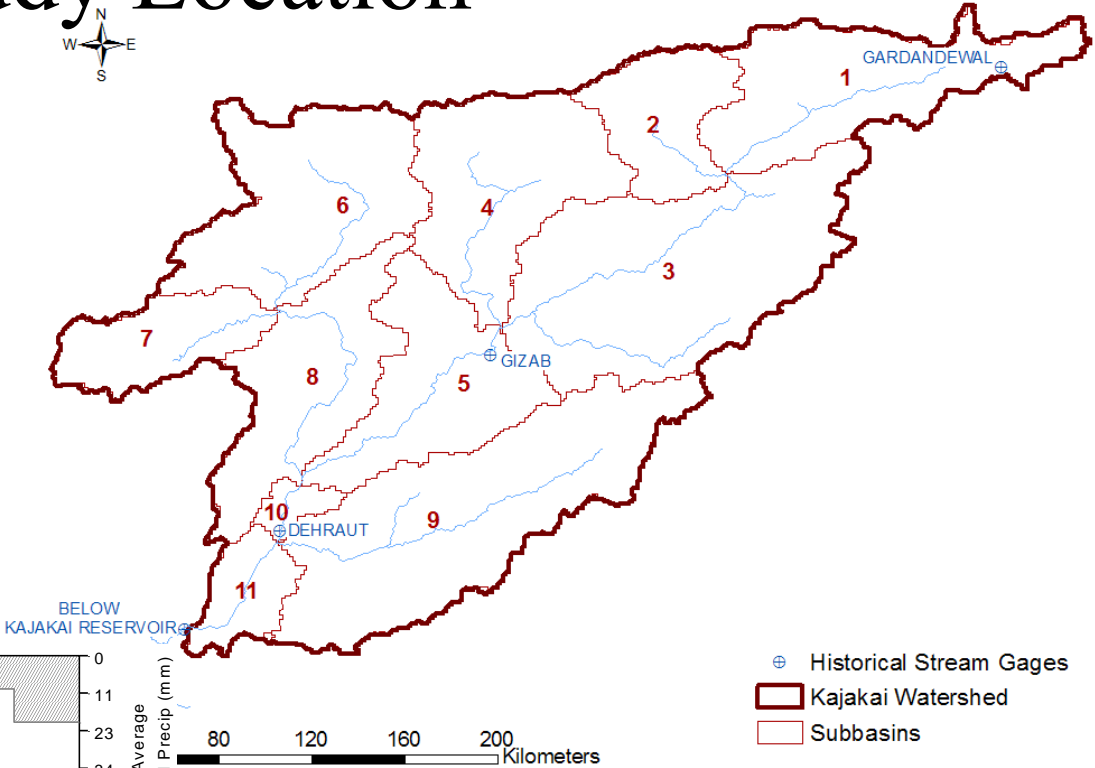
Snow Model - Data

Temperature Data

– 14 stations
– Lapse rate = 5.6°C/km
– 1km² grid size
– Inverse distance weighted interpolation

SHEBERGHAN
MAZAR
FAIZABAD
BAMYAN
LAGHMAN
KABUL
JALALABAD
HIRAT
LOGAR
GARDIZ
GHAZNI
SARDEY
FARAH
KANDAHAR

Temperature Grid (°C)

High : 6.313

Low : -10.605

▲ Temperature Stations

N

0   50 100   200   300   400
Kilometers

Temperature (C) vs Elevation (m) chart with legend: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
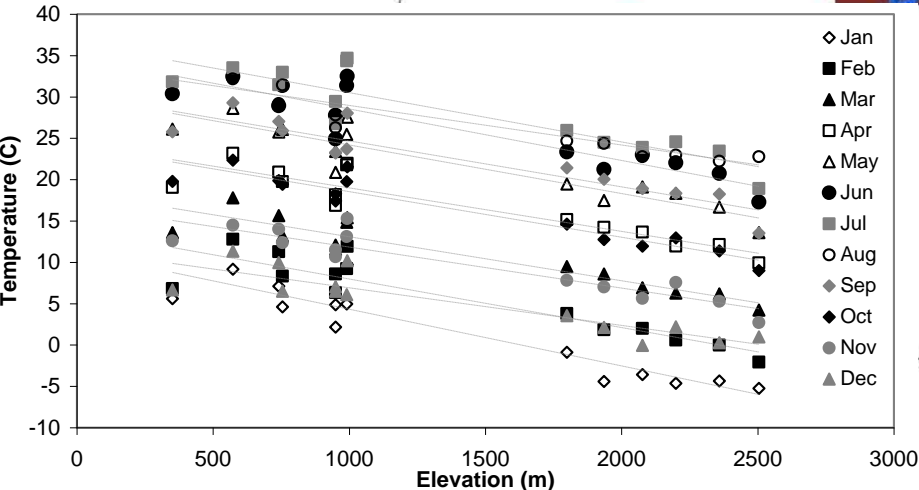
Snow Model - Data

- ## Precipitation Data
  - – Limited gage data
  - – TRMM 3B42 precipitation
  - – Resampled to 1km^2 grids

Snow Model - Calibration

Snow Covered Area, 25 March 2009, Kajakai Watershed
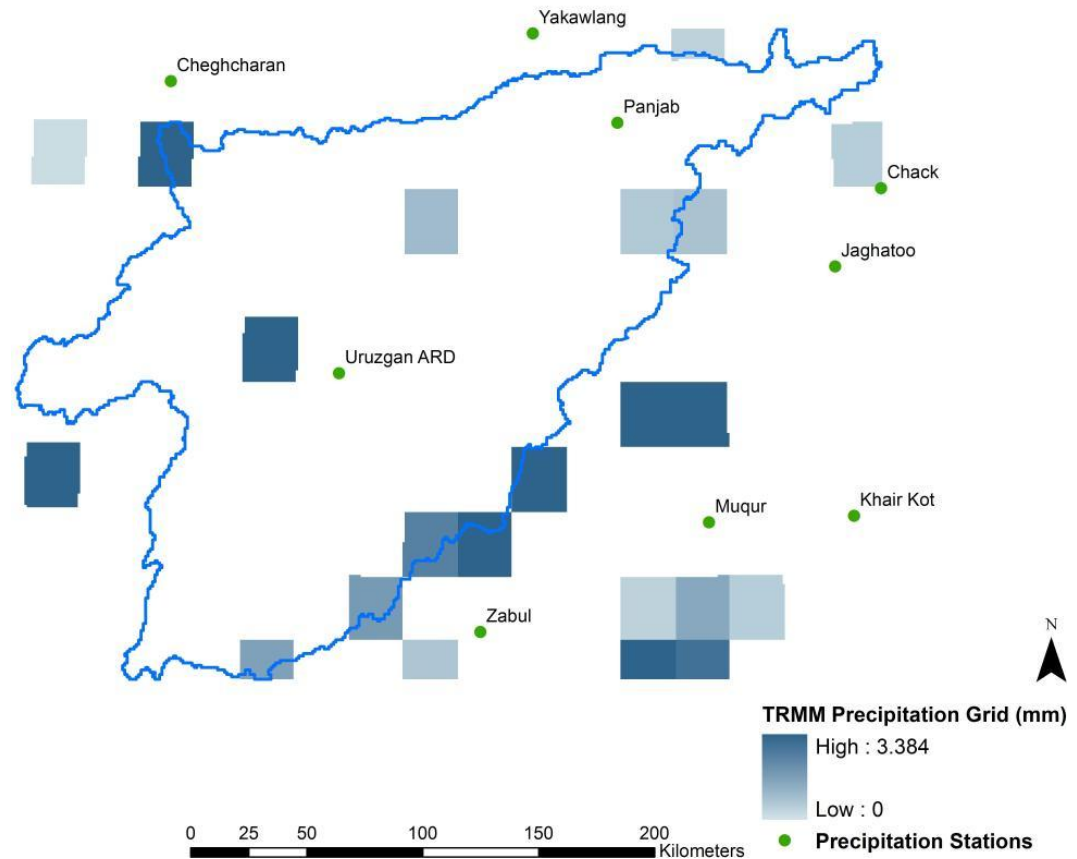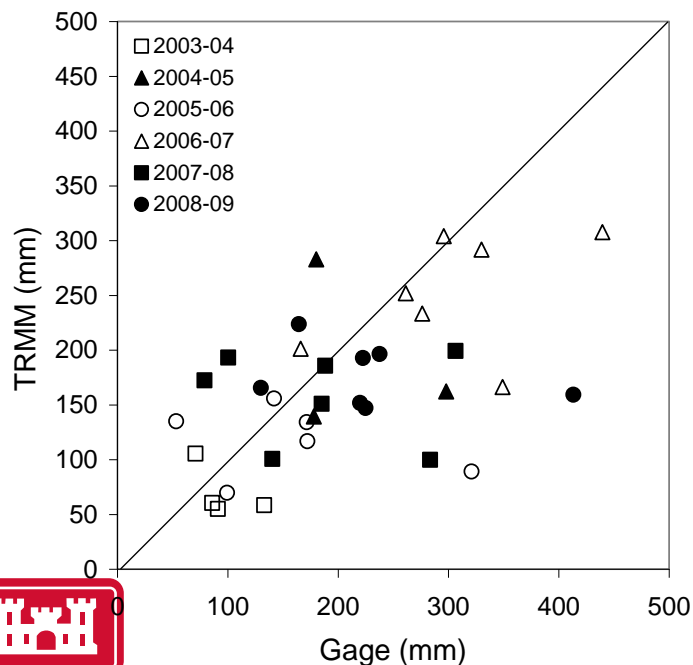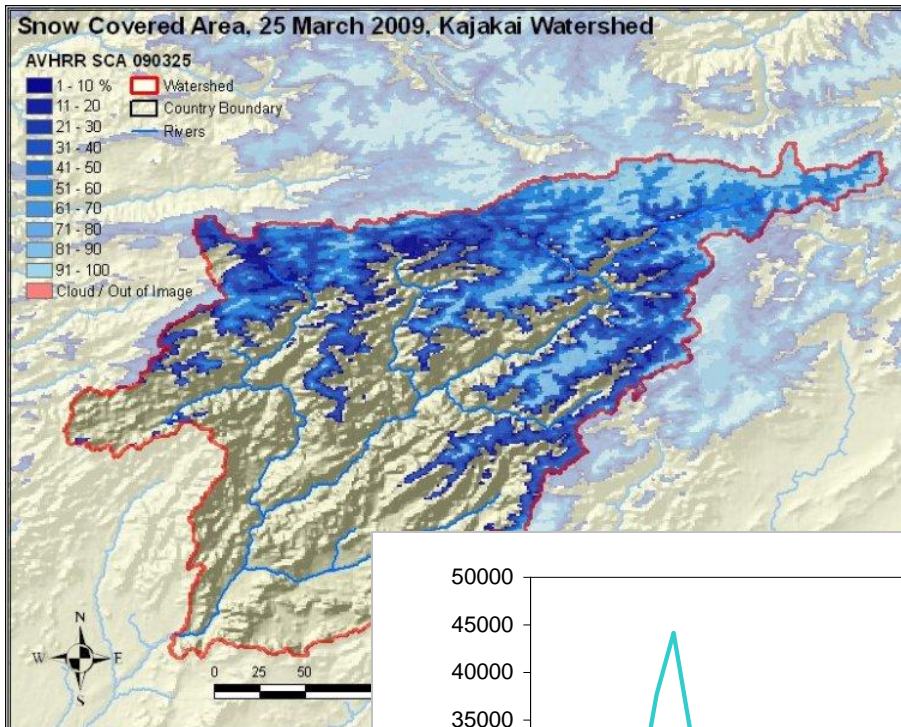
Snow model calibration

– Snow model parameters were calibrated by comparing results spatially against SCA imagery

– High-resolution SCA imagery available from 2006-2009

– $R^2 = 0.86$

– Nash-Sutcliffe efficiency = 0.78

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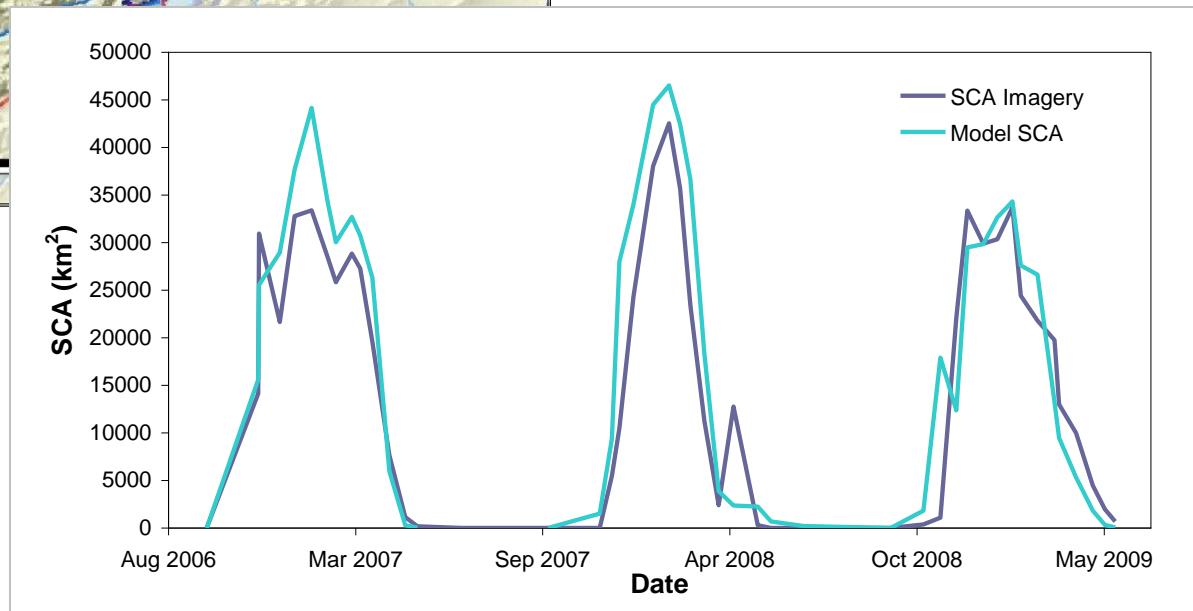
Snow Hydrology Model

Error Matrix Analysis:

- For each image, each pixel was classified as both the model and imagery containing snow, the model or the imagery containing snow but not the other, or neither containing snow.
- An overall accuracy of 85% is considered a reasonable match for error matrix analysis

2006-07

	SCA Imagery		
2006-07	Snow	No Snow	
Snow	257609	54672	312281
No Snow	19508	256006	275514
	277117	310678	587795

Snow Model

overall accuracy: 87.4%
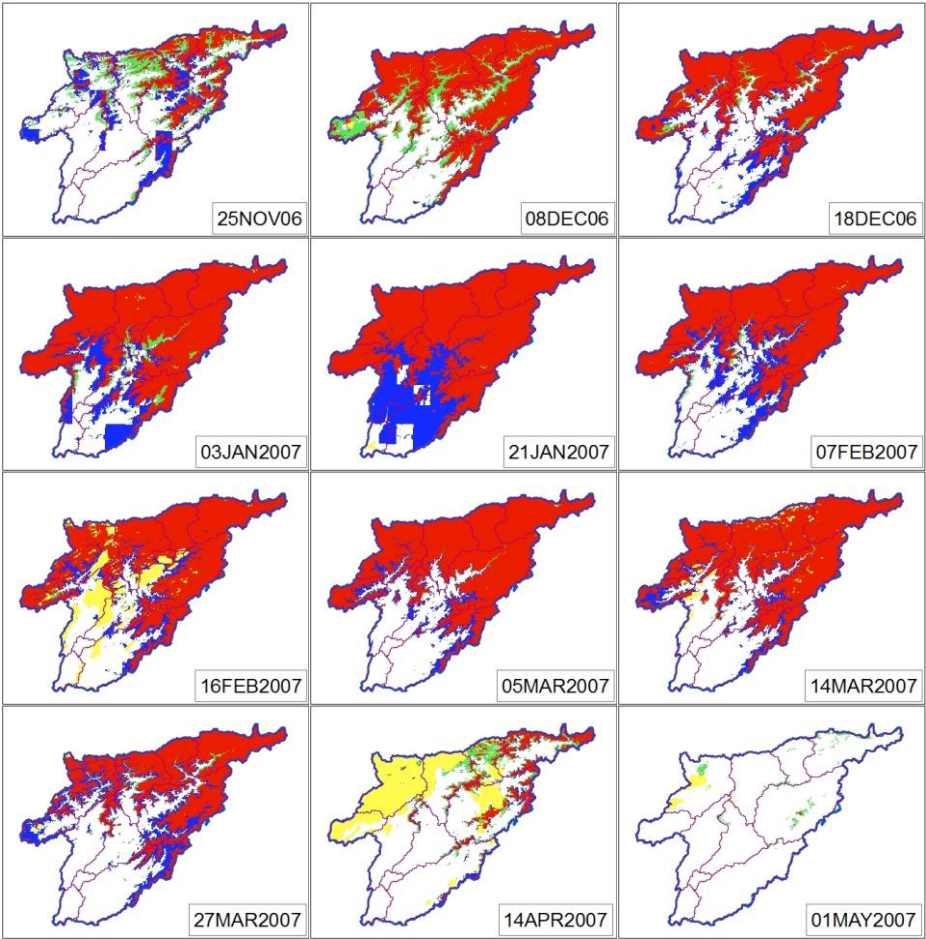
Legend:
- **Both Model and AVHRR** (red)
- **AVHRR only** (green)
- **Snow Model only** (blue)
- **clouds** (yellow)

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Results – SWE Comparison
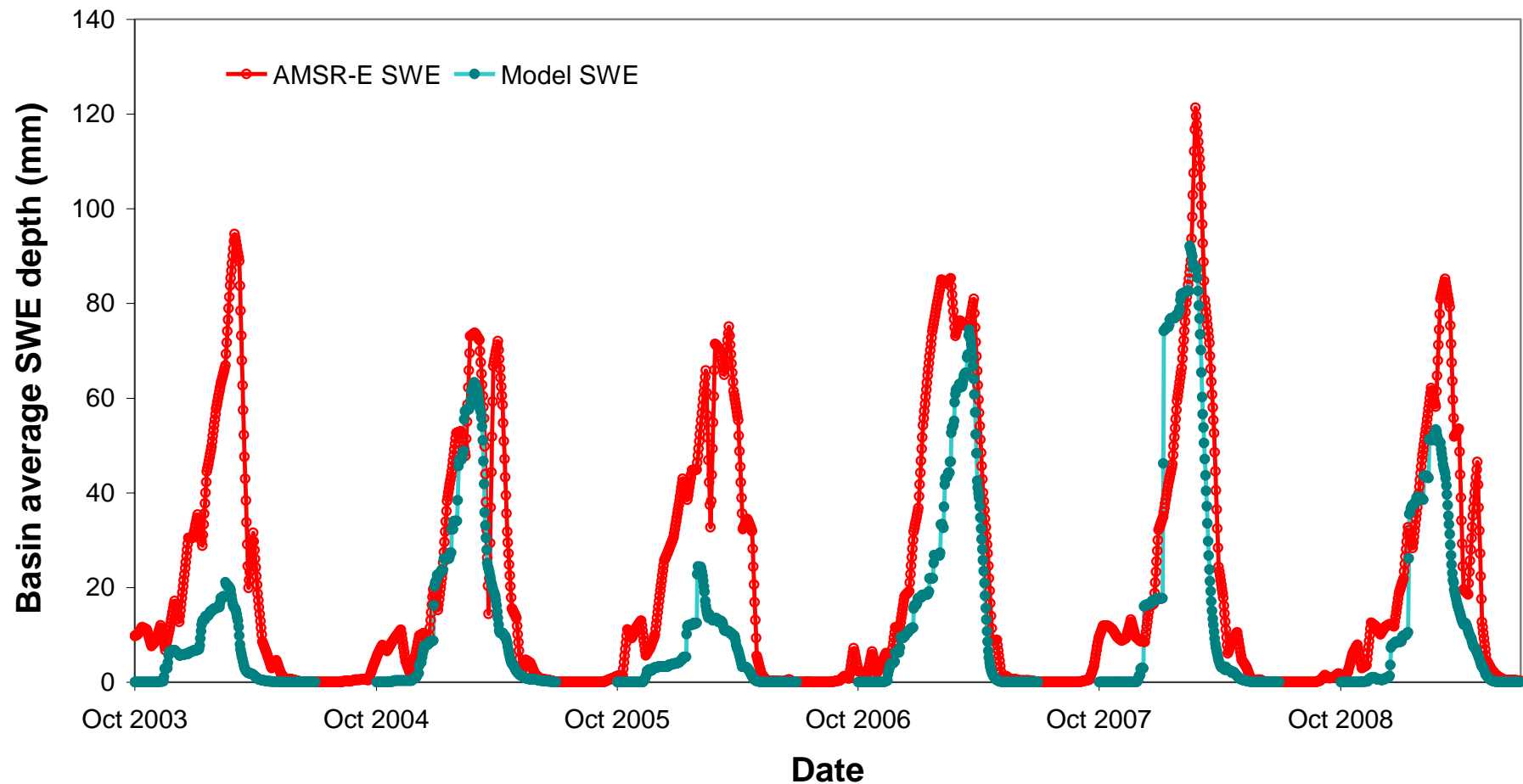
$R^2 = 0.53$

Nash-Sutcliffe efficiency = 0.20 (model as

Reservoir Model

- Reservoir Data available:
  - Monthly reservoir levels, 1998 through present
  - Daily reservoir levels, 2006-07 and 2008-09
  - Elevation-Discharge relationship, includes
    - Irrigation withdrawals
    - Hydropower withdrawals
    - Spillway curve
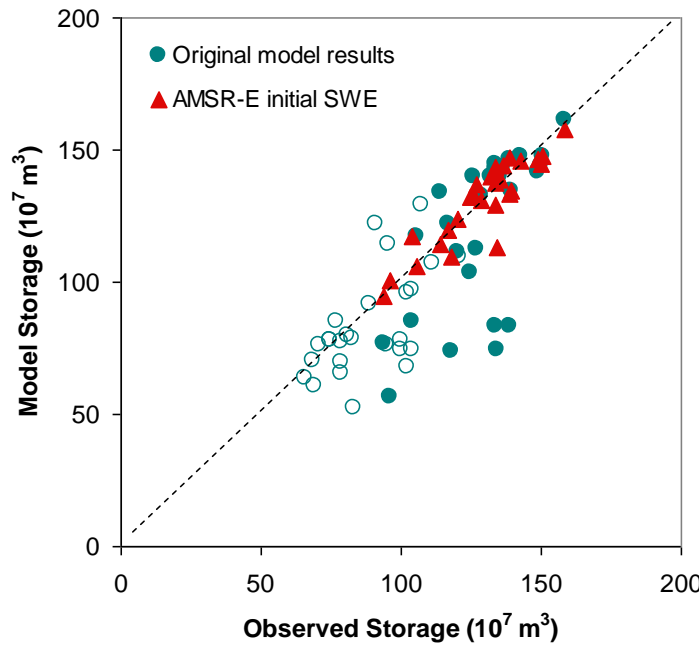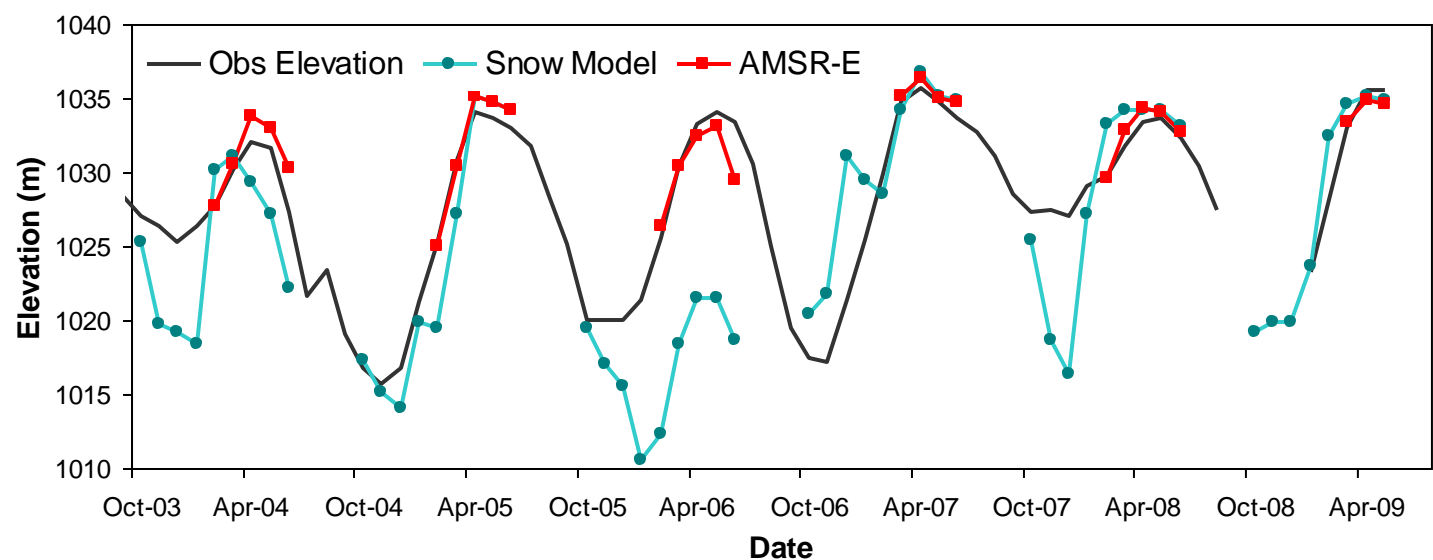 - Elevation – Area – Storage relationship
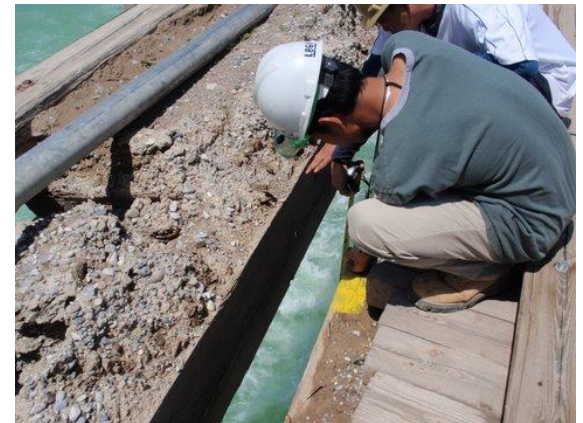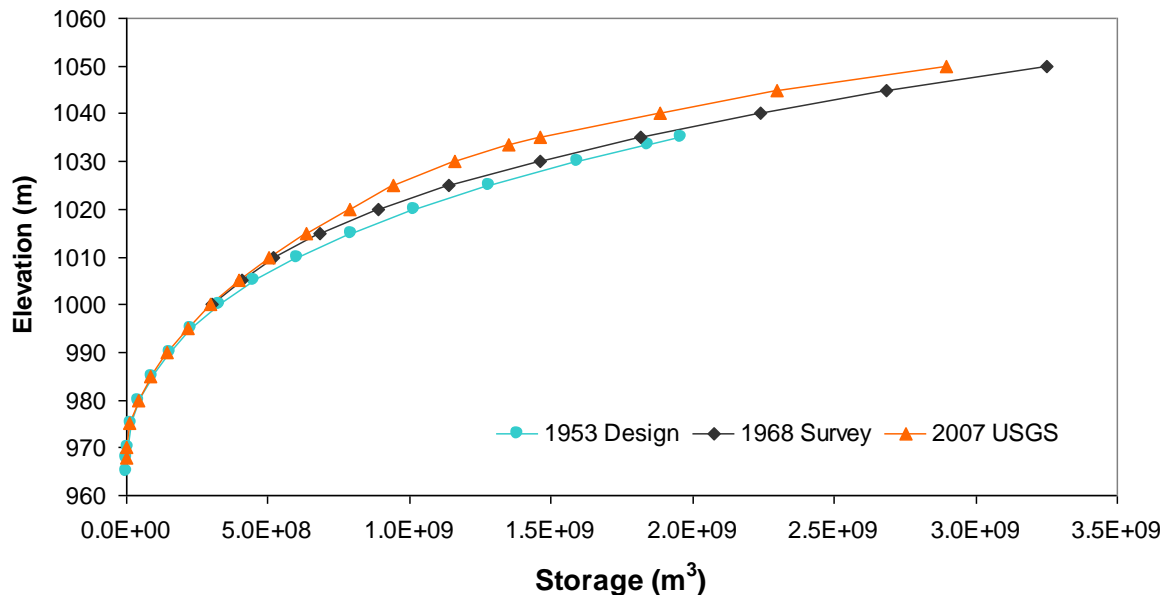
Hydrologic Model

2006-07

Reservoir Inflow (cms)

Water Level (m)
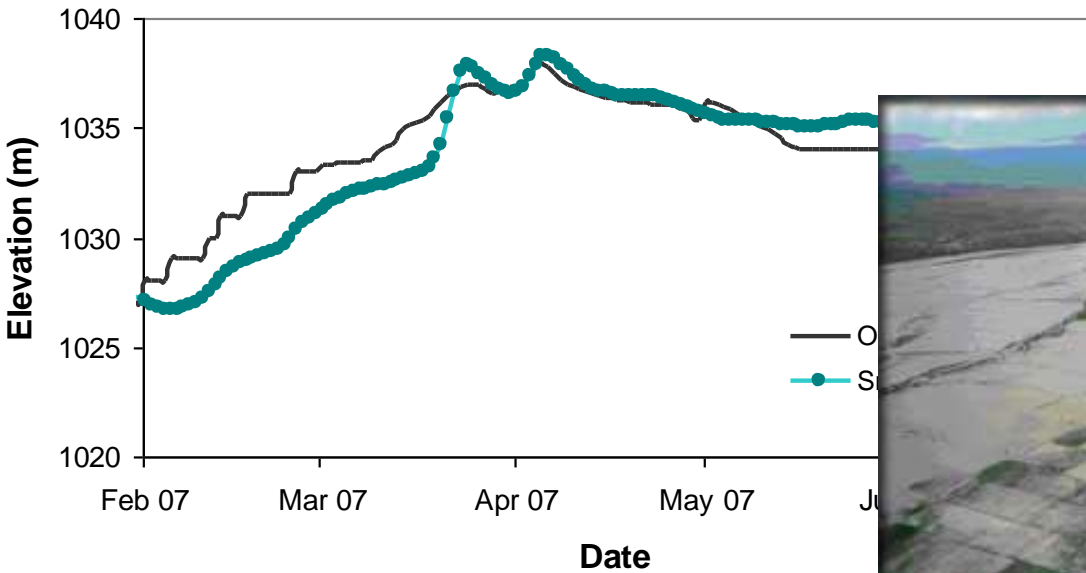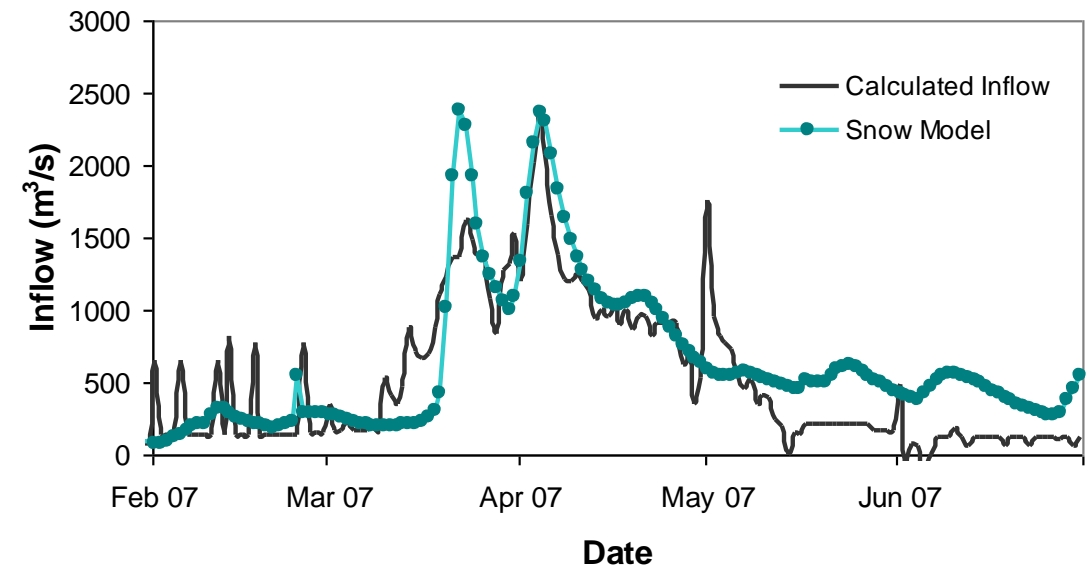
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Using AMSR-E as initial conditions

Monthly average storage

Original model, $R^2 = 0.61$

Initial AMSR-E SWE, $R^2 = 0.81$

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AMSR-E signal observations
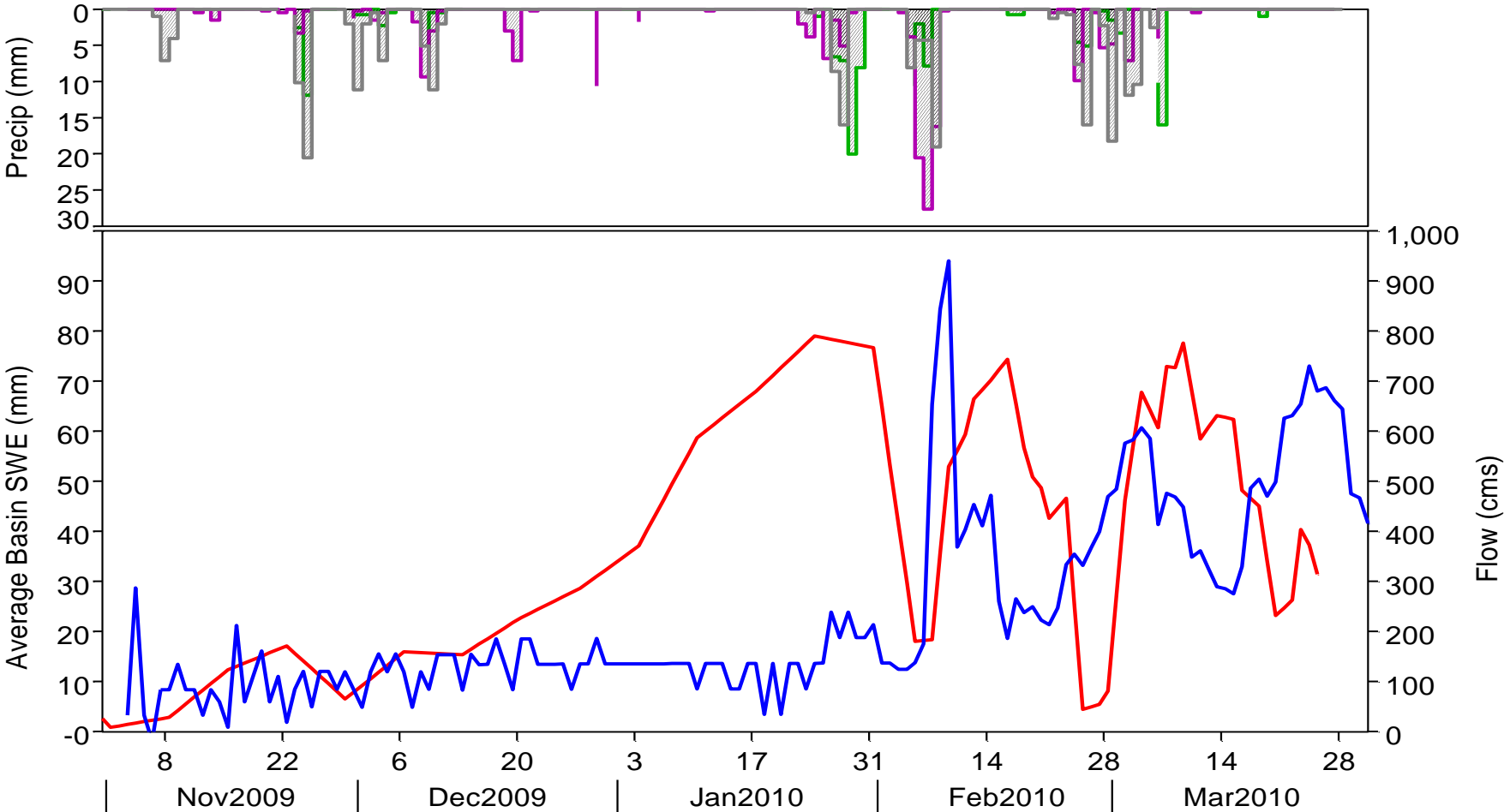
Operational Forecasting

Red River Basin, MN, ND

Red River snow model

Red River Basin, MN, ND
2009 snowmelt flood

Red River Level at Fargo, ND - 2009

March 8, 2009 -> September 1, 2009

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CRREL
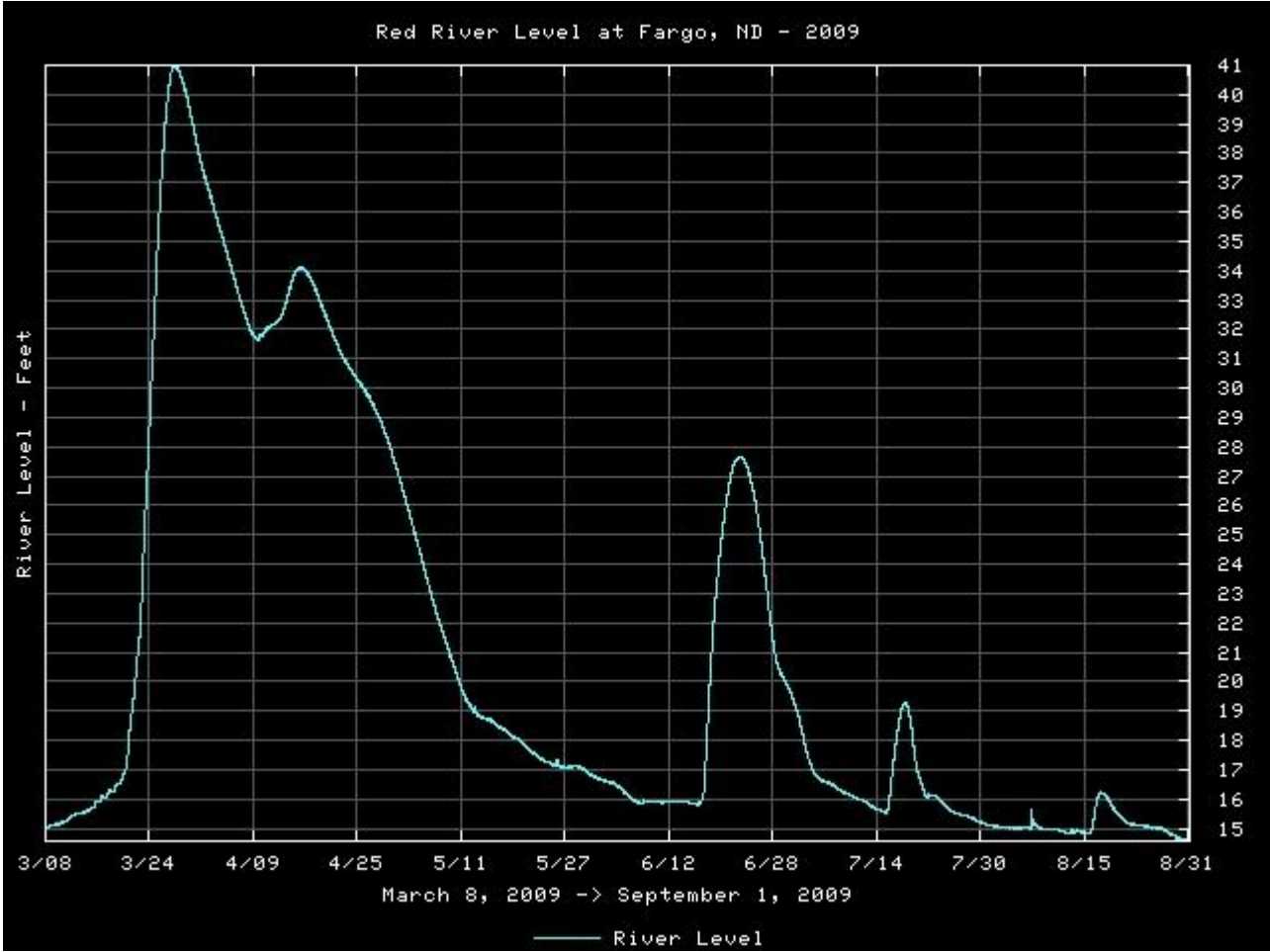
Red River Basin, MN, ND
2009 snowmelt flood

US Army Corps of Engineers
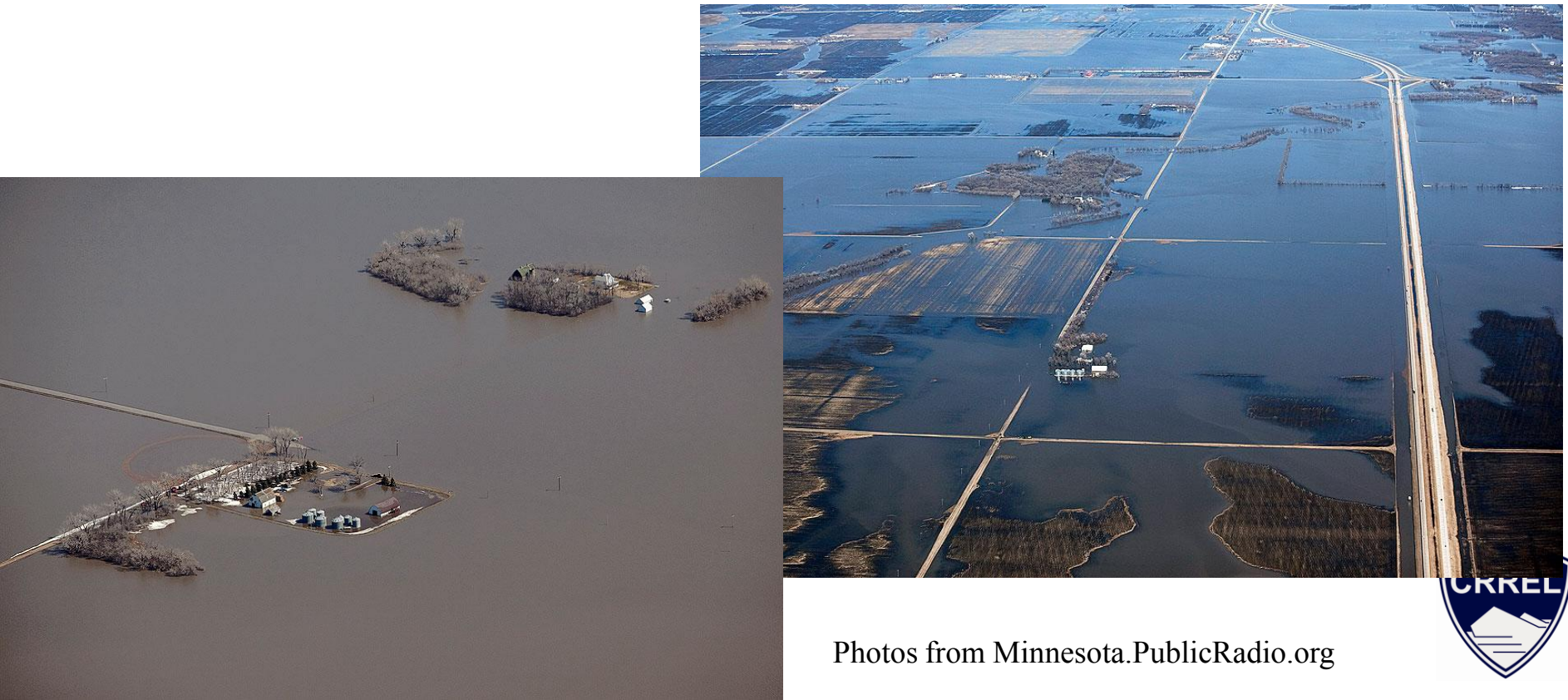
CRREL

Red River Basin, MN, ND
2009 snowmelt flood

CRREL

Red River Basin, MN, ND
2011 snowmelt flood

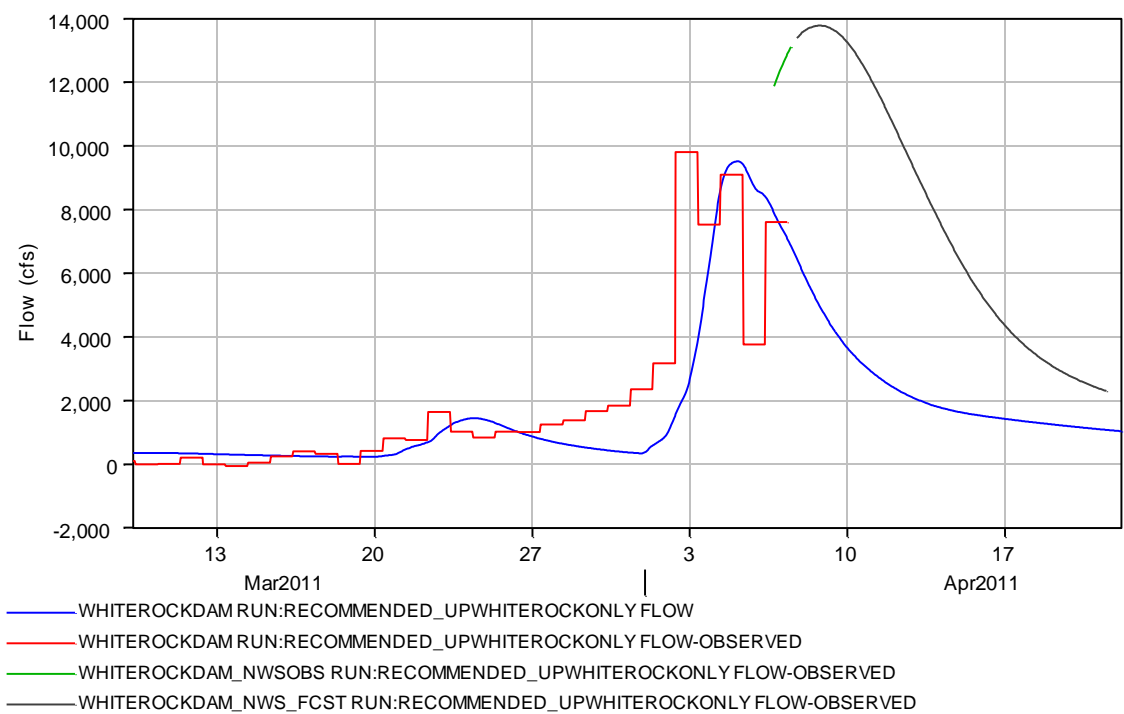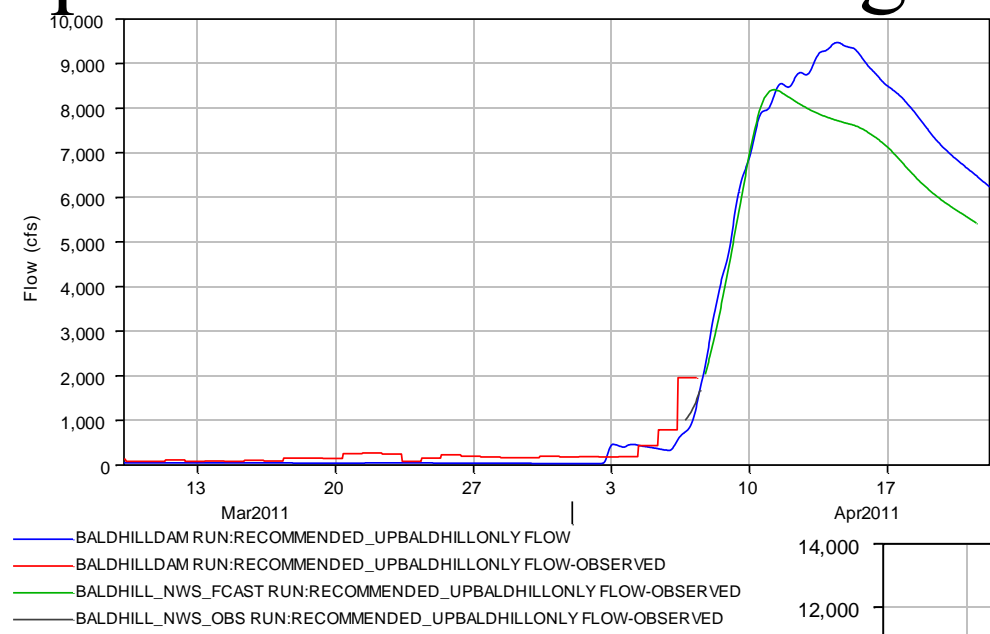http://www.ndsu.edu/fargoflood/snowcover_2011/js_movie.html

http://www.ndsu.edu/fargoflood/stages_2011/fargo_flood.html

Photos from Minnesota.PublicRadio.org

Red River snow model

Operational Forecasting

BALDHILLDAM RUN:RECOMMENDED_UPBALDHILLONLY FLOW
BALDHILLDAM RUN:RECOMMENDED_UPBALDHILLONLY FLOW-OBSERVED
BALDHILL_NWS_FCAST RUN:RECOMMENDED_UPBALDHILLONLY FLOW-OBSERVED
BALDHILL_NWS_OBS RUN:RECOMMENDED_UPBALDHILLONLY FLOW-OBSERVED

WHITEROCKDAM RUN:RECOMMENDED_UPWHITEROCKONLY FLOW
WHITEROCKDAM RUN:RECOMMENDED_UPWHITEROCKONLY FLOW-OBSERVED
WHITEROCKDAM_NWSOBS RUN:RECOMMENDED_UPWHITEROCKONLY FLOW-OBSERVED
WHITEROCKDAM_NWS_FCST RUN:RECOMMENDED_UPWHITEROCKONLY FLOW-OBSERVED

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Snow Mapping

Operational Support:

For the past 6 winter seasons we have provided bi-weekly assessments of the snowpack to U.S. Military personnel in Iraq and Afghanistan. This year Pakistan was also included.

Mission Relevance:
- Operation planning
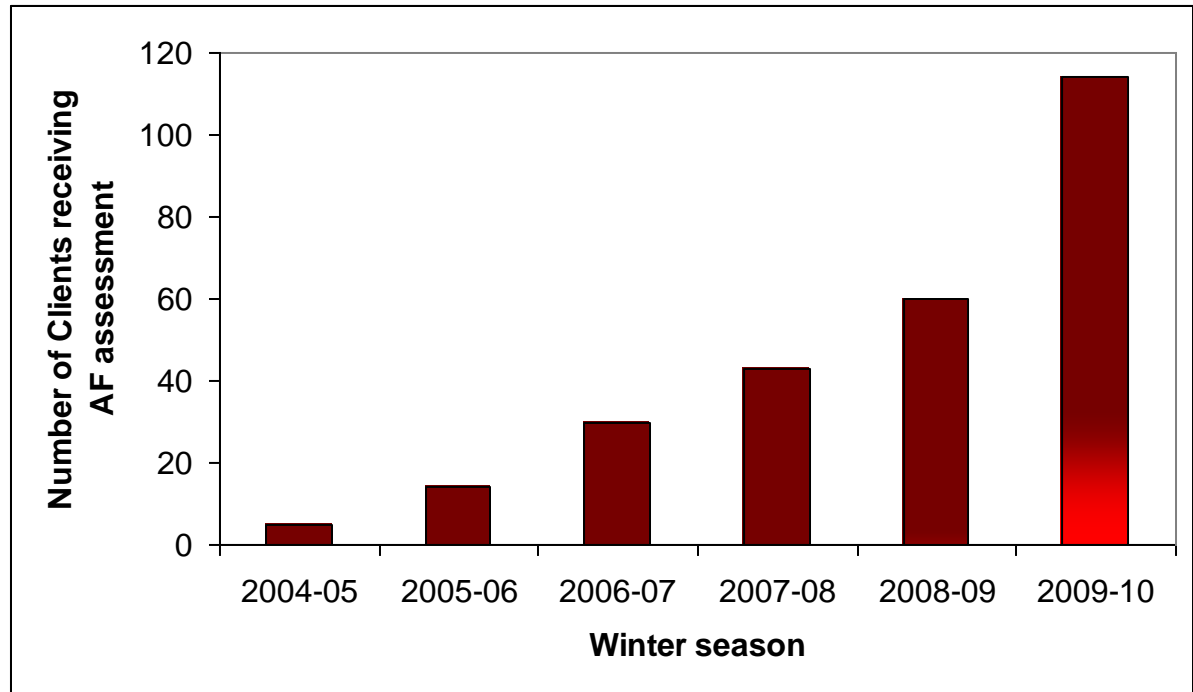- Supplies/Transport
- Flood forecasting
- Water supply

US Army Corps of Engineers

CRREL

Snow Mapping

Clients

- Marine Corps Intelligence Agency
- American Embassy in Iraq
- Iraq Ministry of Water
- U.S. Central Command
- US Army - 82nd Airborne Division
- US Navy
- US Air Force, AFWA
- Canadian Forces
- British Forces
- NATO
- USGS
- USDA
- USAID
- Dept of Disaster Response
- National Geospatial-Intelligence Agency
- German Embassy
- Academic Institutions
- And others

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Snow Mapping

Application:
- The snow assessments use satellite imagery to analyze the snowpack.
- Assessments are sent by email every two weeks starting in November and going through May.

Each assessment includes:
- Snow covered area (SCA) map
- SCA by Elevation Band
- Snow Water Equivalent (SWE) charts
- General assessment of snowpack and flood risk
  - Summary of SCA and SWE data
  - Comparison to previous assessments
  - Summary of meteorological data
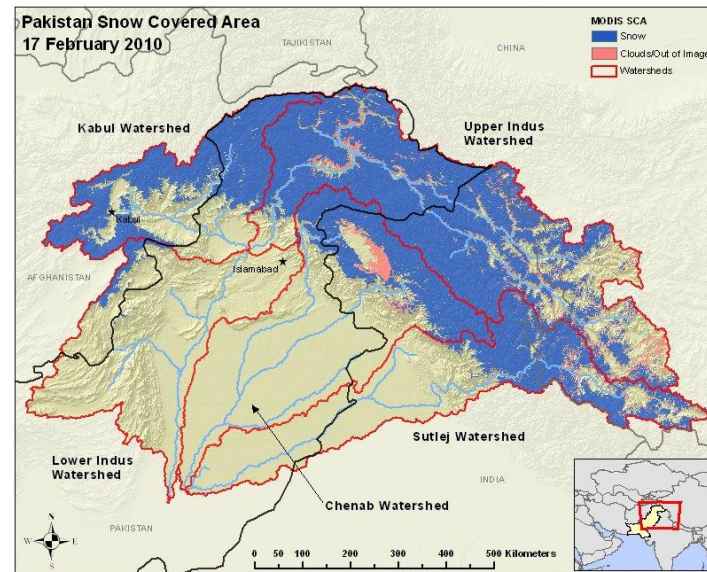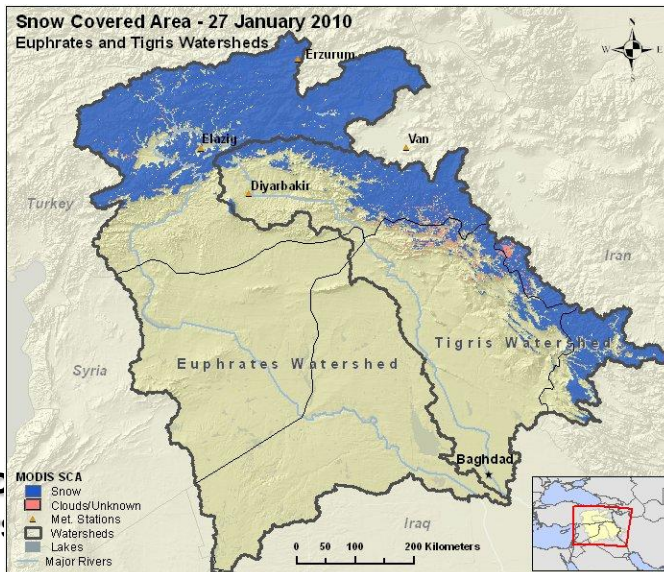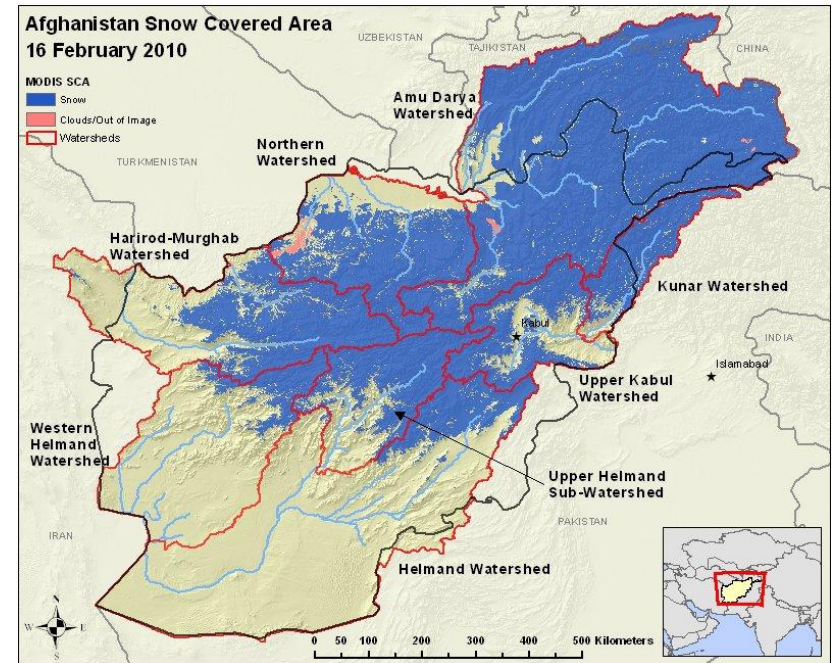 - Flood risk assessment
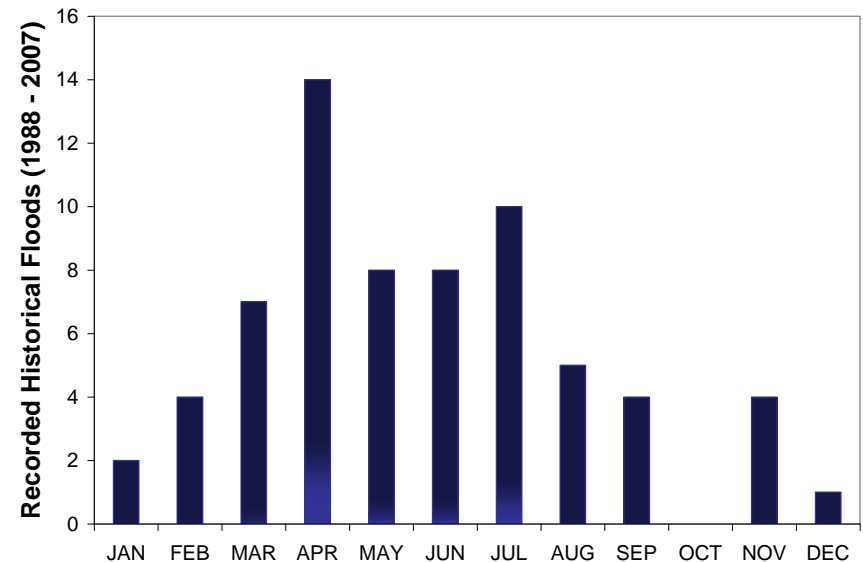
Additional Product:
- SCA shapefiles
- Google earth snow cover

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Snow Mapping

Snow Covered Area Map

- Advanced Very High Resolution Radiometer (AVHRR) / Moderate Resolution Imaging Spectroradiometer (MODIS)
- Algorithms developed to remove clouds

Snow Mapping

SCA by Elevation Band

Euphrates River Watershed in Turkey

Elevation Band (m)	Area (km^2)	SCA (km^2) 29-Oct-07	SCA (km^2) 12-Nov-07	SCA (km^2) 26-Nov-07	SCA (km^2) 8-Dec-07	SCA (km^2) 24-Dec-07	SCA (km^2) 7-Jan-08	SCA (km^2) 21-Jan-08
0-500	8025	0	0	0	0	0	0	0
501-1000	31215	0	10	5	8	13	3676	1454
1001-1500	25838	0	2660	309	1906	3787	21215	16161
1501-2000	37295	0	18721	5517	16973	29524	36880	34611
2001-2500	15438	13	13211	9204	8161	15075	15396	15208
2501-3000	3811	160	2951	3382	1967	3765	3806	3806
3001-3500	260	1	103	239	185	254	260	260
3501-4000	3	0	0	3	0	2	3	3

* The SCA is potentially under-represented because significant portions of these elevation bands were obscured by cloud cover.
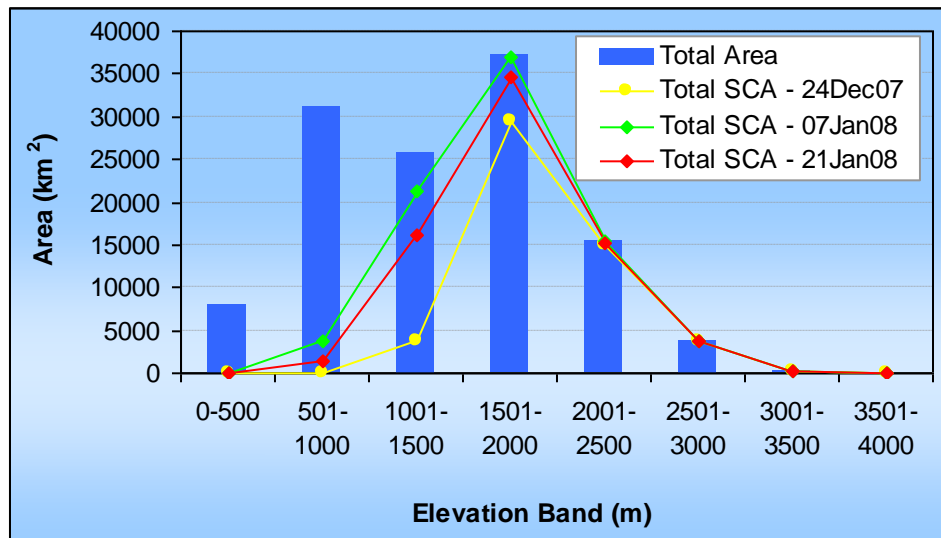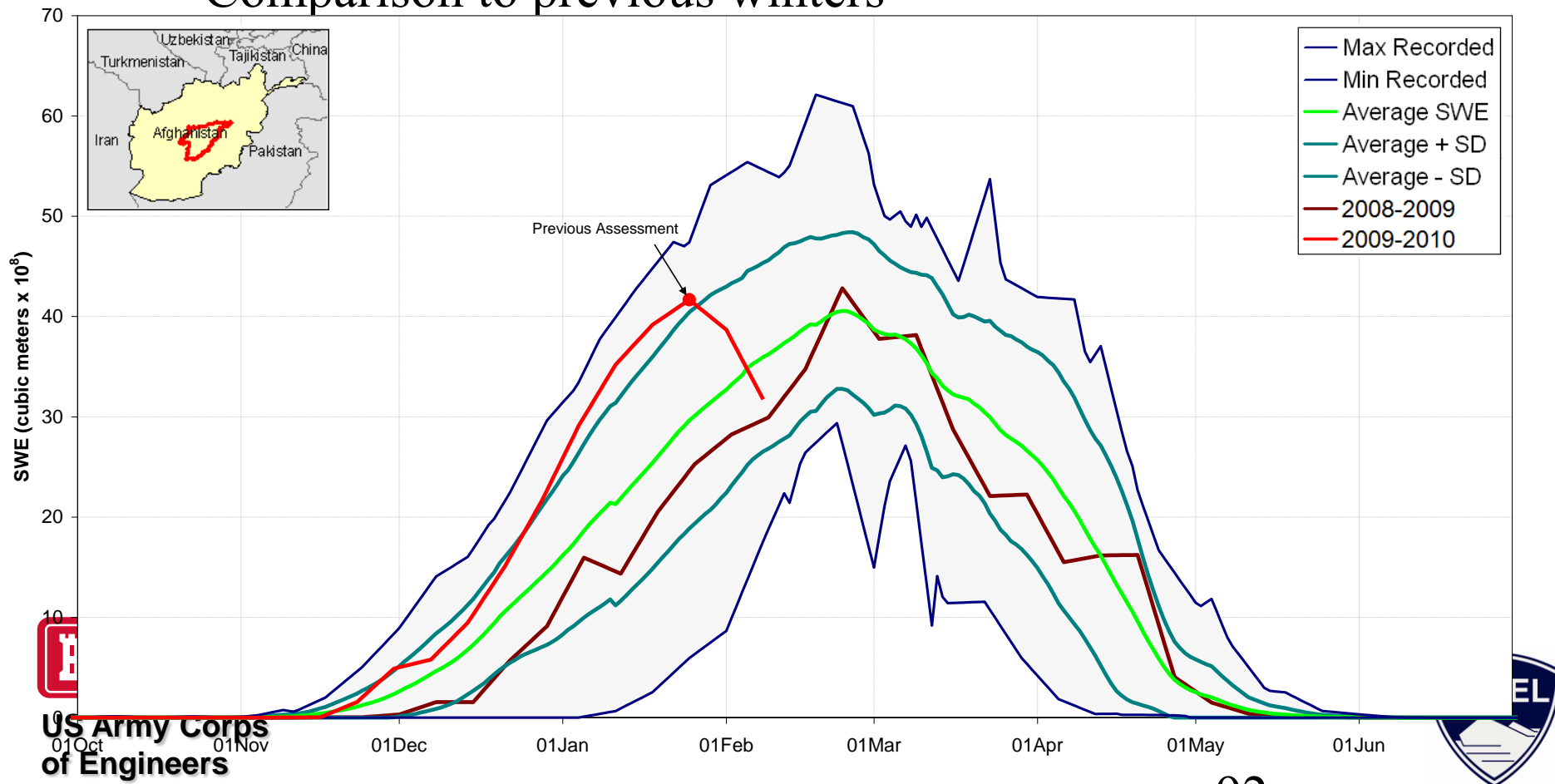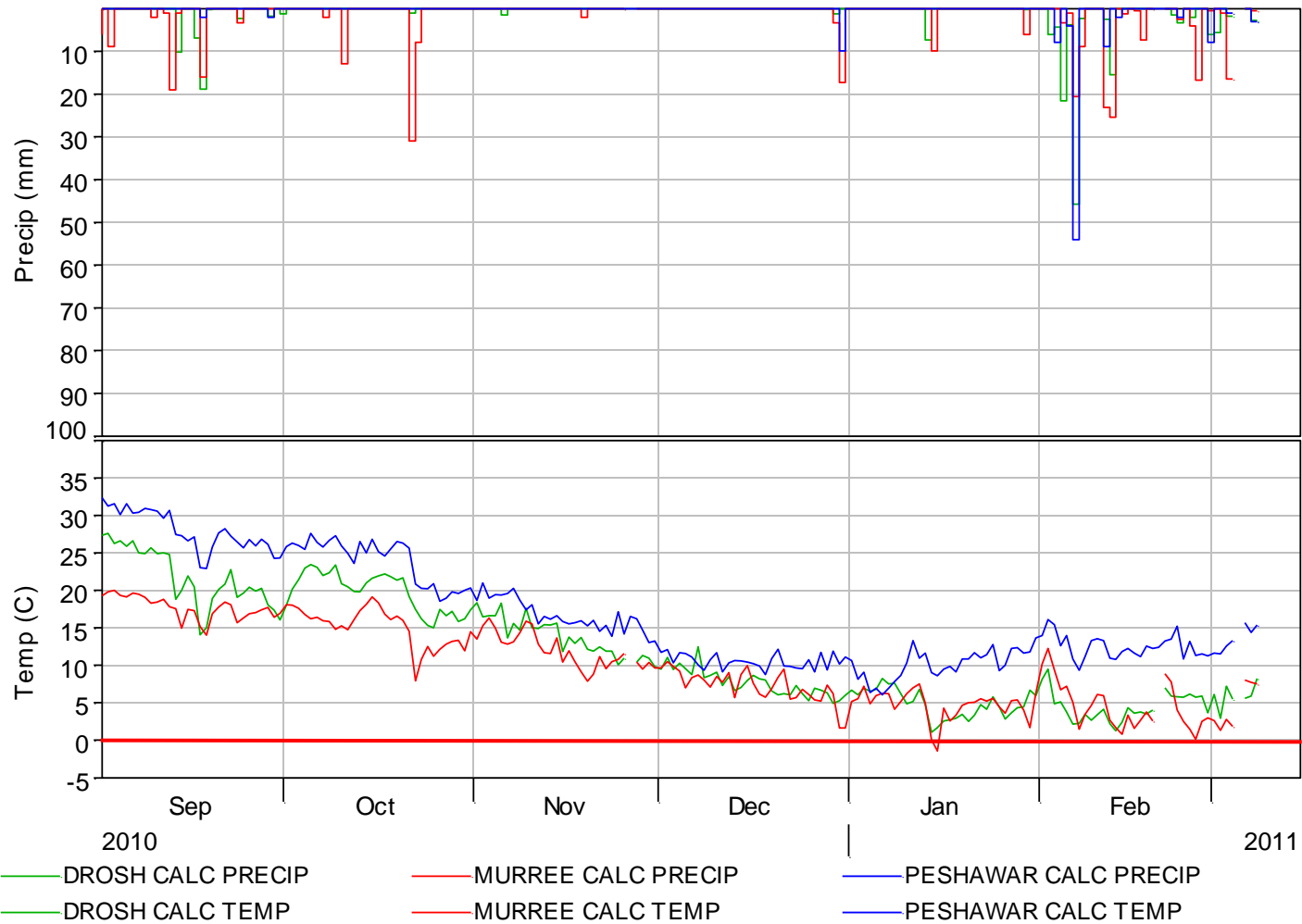
Snow Mapping

Snow Water Equivalent Charts
- Special Sensor Microwave/Imager (SSM/I)
- Relative volume of SWE
- Comparison to previous winters

Pakistan Meteorological Data

Limited air temperature (C) and precipitation (mm) data were obtained from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html)
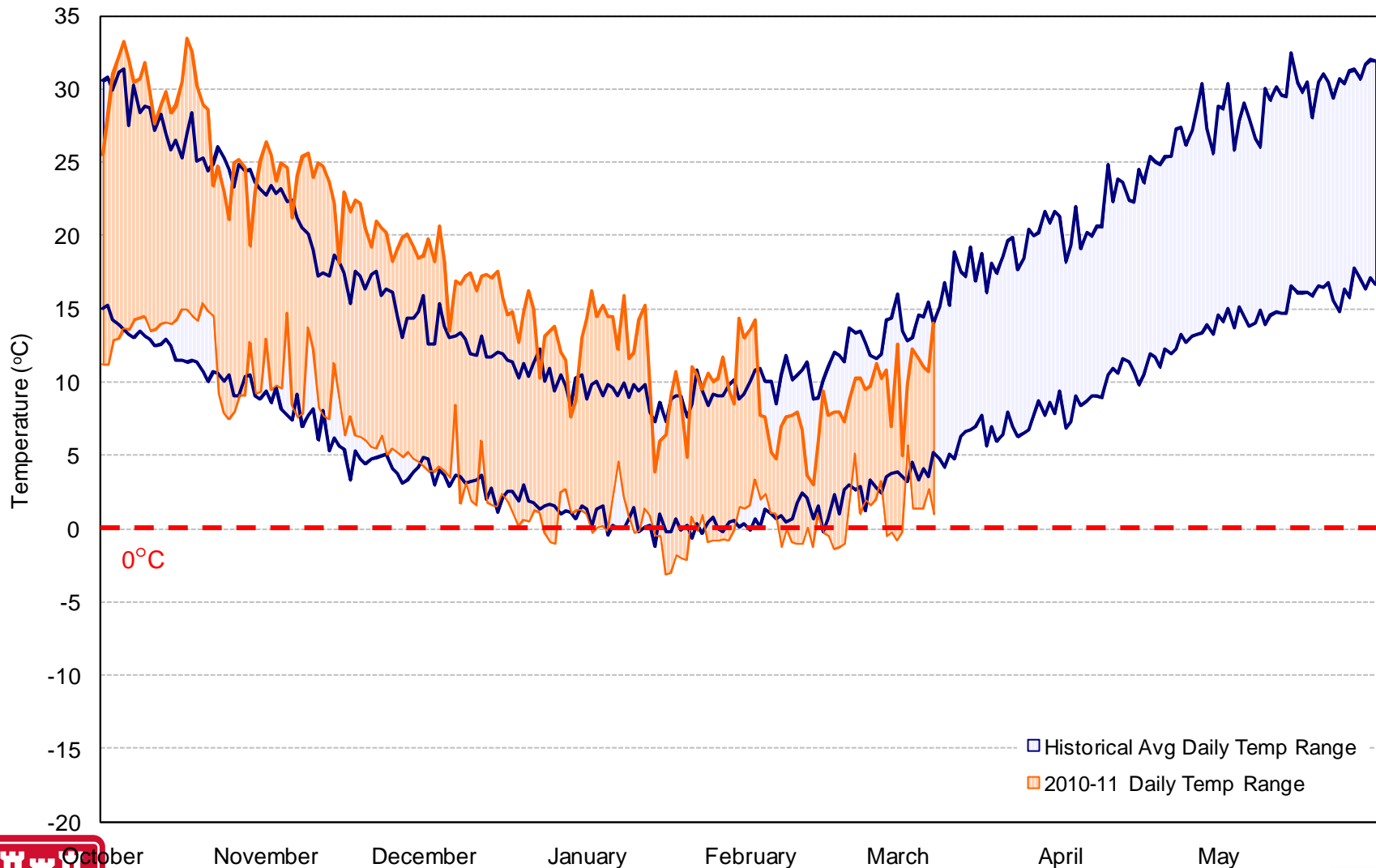Station: Drosh, Kabul Watershed, elevation 1465m
Station: Murree, Lower Indus Watershed, elevation 2127m
Station: Peshawar, Kabul Watershed, elevation 360m

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Drosh Temperature Comparison

Historical data obtained from the National Climatic Data Center, 1957 – 1966

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Summary Operational Snow Melt Hydrology

- Depends on data from many sources: Course, point, distributed

- Watershed SWE: GIS to combine course, point, and distributed data

- Forecasting
  - Models, meteorology, climatology

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